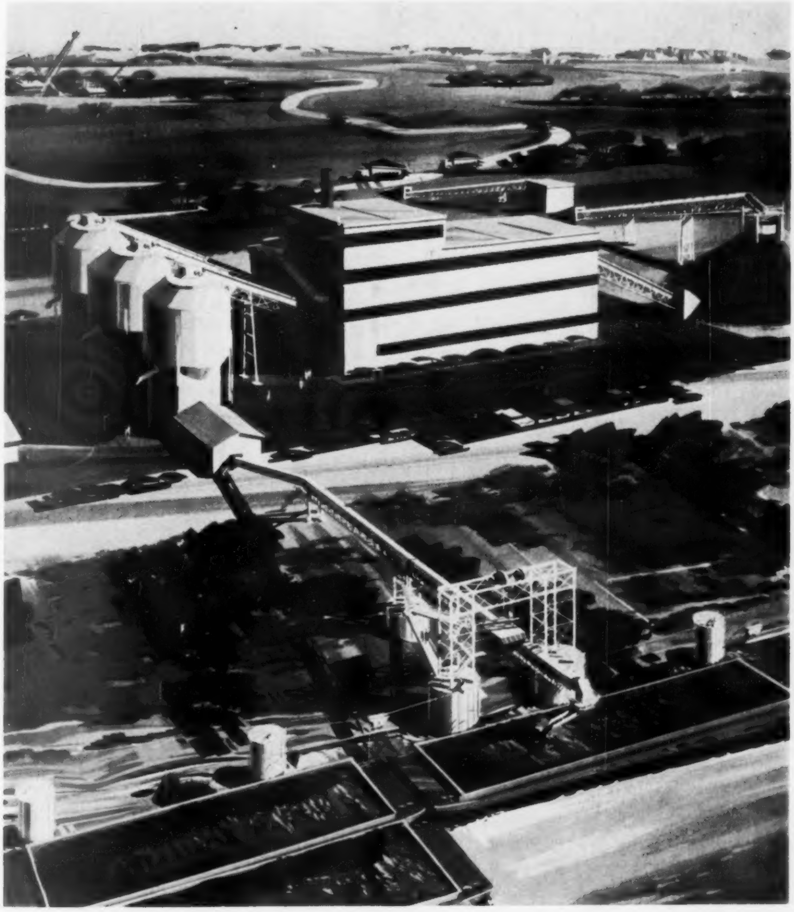
Combustion

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

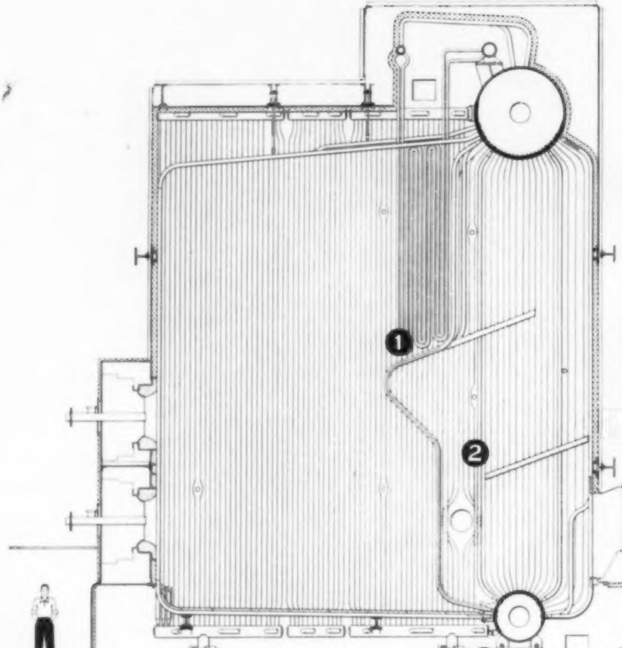


tember 1961

Combined Steam and Gas Turbine Cycles

Combustion Control For Two Solid Fuels

Solid State Electric Control For Boilers



VU-60

THE NEW C-E BOILER THAT'S CUSTOM-DESIGNED FROM MODULAR COMPONENTS

1 The VU-60 can operate over a wide load range while maintaining superheated steam temperatures close to the design point.

2 Cross-flow baffling and symmetrical boiler bank assure low draft loss, eliminating sluggish flow in any pass.

3 Only a simple reinforced-concrete slab is required. No conventional roller supports are needed.

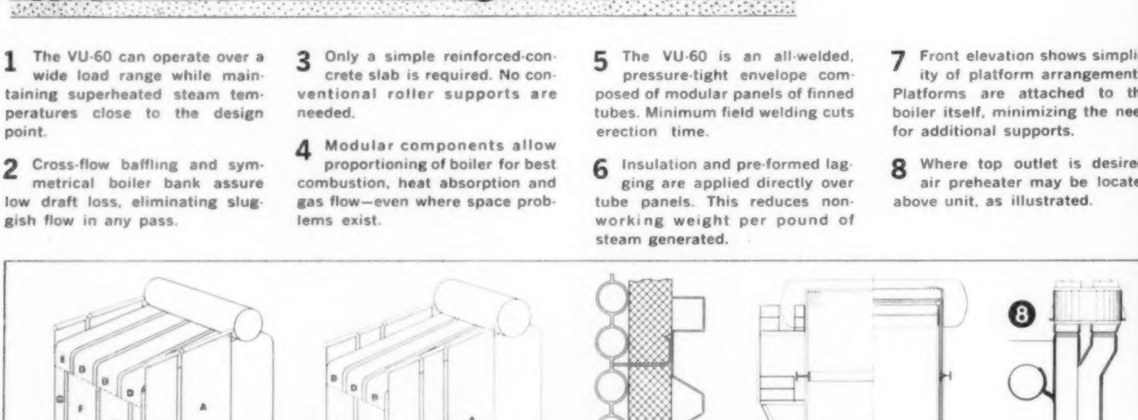
4 Modular components allow proportioning of boiler for best combustion, heat absorption and gas flow—even where space problems exist.

5 The VU-60 is an all-welded, pressure-tight envelope composed of modular panels of finned tubes. Minimum field welding cuts erection time.

6 Insulation and pre-formed lagging are applied directly over tube panels. This reduces nonworking weight per pound of steam generated.

7 Front elevation shows simplicity of platform arrangements. Platforms are attached to the boiler itself, minimizing the need for additional supports.

8 Where top outlet is desired, air preheater may be located above unit, as illustrated.



VU-60 SPECIFICATIONS

Capacities:	100,000 to 250,000 lb/hr
Design pressures:	250, 500, 750, 1040 psi
Steam temperatures:	to 900F
Fuels:	Oil and/or gas
Firing:	Horizontal (front wall) or tangential
Size increments:	Depth—twelve Width—eight Height—three
Steam drum sizes:	Four

The VU-60 can be designed to meet your most exacting steam needs. It's easy to install, economical and reliable in operation, completely accessible and functional. Get full information on how this new concept can fulfill your specialized requirements.

COMBUSTION ENGINEERING

C-332

General offices: Windsor, Connecticut
New York offices: 200 Madison Avenue, New York 16

ALL TYPES OF STEAM GENERATING, FUEL BURNING AND RELATED EQUIPMENT; NUCLEAR REACTORS; PAPER MILL EQUIPMENT; PULVERIZERS; FLASH DRYING SYSTEMS; PRESSURE VESSELS; SOIL PIPE

Combustion

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

volume 33 number 3 **September 1961**

The Theory of Combined Steam and Gas Turbine Installations . . . 30

C. Seippel and R. Bereuter

An excellent survey of the basic combinations worthy of consideration and a scholarly discussion of their workings and their thermodynamics

A Concept of Combustion Control for Firing Two Solid Fuels . . . 43

Carl E. Rodenburg

Controls of a single solid fuel aided by either a gas or an oil fuel lend themselves to proved treatments. Two solids, however, can mean problems. Here is one of the better approaches we have seen.

Application of Solid State Electric Control to Utility Boilers . . . 48

E. E. Swanson

The age-old handling of boiler controls by separate checks on separate functions has lost out to the need for full process loop controls. This article discusses control devices

Abstracts From the Technical Press—Abroad and Domestic . . . 54

Editorial: Plain Words

Capricorn . . . **29**

Advertising Index . . . 60, 61

JOSEPH C. McCABE, ***Editor and Publisher***

A. W. HINDENLANG, ***Associate Editor***

ROBERT D. TAFT, ***Business Manager***

MISS MARY MONGAN,
Circulation Manager

Published monthly by COMBUSTION PUBLISHING COMPANY, INC., 200 Madison Ave., New York 16. A SUBSIDIARY OF COMBUSTION ENGINEERING, INC.

Charles McDonough, President

Arthur J. Santry, Jr., Vice-President

Lambert J. Gross, Treasurer

Thomas A. Ennis, Secretary

COMBUSTION is sent gratis to engineers in the U. S. A. in charge of steam plants from 20,000 lbs per hr capacity up; and to consulting engineers in this field. To others the subscription rate, including postage, is $4 in the United States, $5.50 in Canada, and $8 in Latin America and other countries. Single copies: Domestic, 40 cents, Foreign, 60 cents plus postage. Copyright 1961 by Combustion Publishing Company, Inc. Publication Office, Easton, Pa. Issued the middle of the month of publication.

Accepted as controlled circulation publication at Easton, Pa.

COMBUSTION publishes its annual index in the June issue and is indexed regularly by Engineering Index, Inc. and also in the Applied Science & Technology Index.

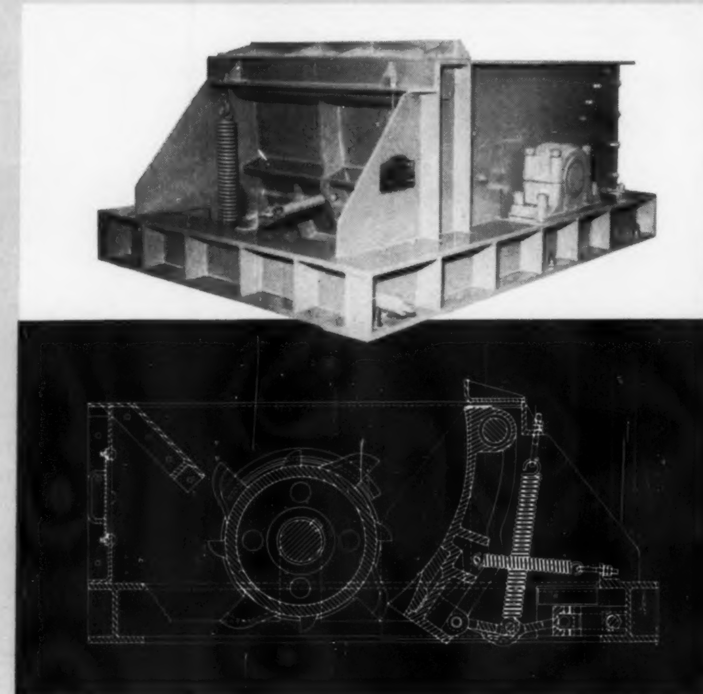
The magazine is now reproduced and distributed to libraries on microfilm by University Microfilms of Ann Arbor, Michigan.
Printed in U. S. A. BPA

COVER PHOTO

The first direct barge loading coal mine in Illinois, the Banner Mine of the United Electric Coal Companies

CRACK THE PROBLEM OF HANDLING NEXT WINTER'S FROZEN COAL—NOW!

Pennsylvania's Frozen Coal Cracker is the answer



If frozen coal handling is one of your winter problems—you can solve it with a Pennsylvania Frozen Coal Cracker.

This is the specially-developed cracker with a *wide feed opening*, permitting use of *open-throated* hoppers. Dumped directly into such hoppers (no need for grates) the frozen masses of coal work their way freely to the hopper bottom where they are broken up by blows from the cracker's special teeth.

A uniform product with limited top size and minimum fines is fed conveyors, protecting them from overload, and insuring a continuous flow of coal from unloading point to yards, or yards to plant.

Cracker can be started up with full hopper; operates satisfactorily under choke feed.

Breaker plates are designed so that in warm weather they can be opened up, permitting the coal to pass through without operating the crusher.

Mechanically simple, built-in tramp iron protection. Low headroom required makes the Frozen Coal Cracker ideal to fit into existing hoppers. Drives can be engineered to fit in a minimum of space. Capacities up to 1200 tons per hour. Available in single or twin units.

ACT NOW

Don't be plagued by hopper jams, overloaded conveyors, slowdowns and high labor costs. Act now. Write for new Bulletin 2013.

PENNSYLVANIA CRUSHER DIVISION
BATH IRON WORKS CORPORATION
WEST CHESTER, PENNA.

★ ★ ★

Over 50 years' concentrated experience in all types of material reduction makes Pennsylvania your best source of crushers and engineering advice and service. Call on Pennsylvania with your next crushing problem. Representatives from coast-to-coast.

PENNSYLVANIA
BATH-BUILT
CRUSHERS

This compact Package Air Preheater is being installed on a 150,000 lb/hr boiler at Olin Mathieson Chemical Corp.'s Brandenburg, Kentucky, petrochemical plant. When in operation it will recover enough heat from the boiler exhaust to increase efficiency of the boiler between 8% and 9%.

OLIN MATHIESON RECOVERS 360°F FROM BOILER EXHAUST WITH 11½′ x 11′ x 8′ PREASSEMBLED LJUNGSTROM® PACKAGE AIR PREHEATER

Olin Mathieson specified a Ljungstrom Package Air Preheater because it saves space as well as fuel. Mathieson's Ljungstrom occupies only about 1000 cubic feet, but cuts boiler exhaust temperature from 680°F to 320°F — puts 360° of heat back to work in the boiler.

The compact preassembled Package Air Preheater is ready to run when it's delivered—just connect to the power line and ducts, and it's on-stream. You make big savings on installation because there's no on-the-spot erection.

You can use a Ljungstrom Package Air Preheater on boilers from 25,000 to 250,000 pounds of steam per hour. For more information, write today for your free copy of a 14-page booklet.

THE AIR PREHEATER CORPORATION

60 East 42nd Street, New York 17, N. Y.

YARWAY Y news briefs

from **Yarnall-Waring Company,** *Philadelphia 18, Pa.*
BRANCH OFFICES IN 19 UNITED STATES CITIES • SALES REPRESENTATIVES THROUGHOUT THE WORLD

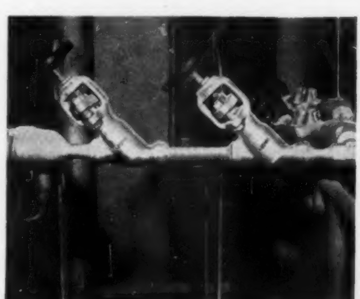
WHY YARWAY WELBONDS ARE SPECIFIED FOR HIGH PRESSURE VALVE JOBS

Yarway Welbond Valves (sizes ¼" through 2½") have won resounding acceptance from boiler room operators everywhere because of these 6 unique features—resulting in *outstanding performance* that is *dependable* and *trouble-free:*

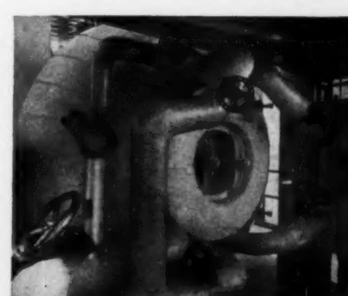
1. Full **accessibility**—all working parts readily removed through top of yoke. Jack action of stem forces out old packing.
2. Guided valve stem of **#321 stainless steel**—will not "pit." Self-aligning, stellite-faced disc.
3. High temperature **inhibited stem packing** furnishes double insurance against packing leaks.
4. Unique seat design with thermal compensating groove that **prevents distortion** during assembly welding and when welding valve into line. Also permits perfect seating of disc for tight seal. Integral seat is stellite-faced.
5. **One-piece** forged chrome-moly steel body and yoke.
6. Easy-grip, **ventilated handwheel**—makes operating a "breeze".

More details—and list of users? Write Yarway. Ask for Bulletin B-454.

Four of many Yarway Welbonds installed in large eastern public utility plant. Steam pressure 1850 psi; temperature 1000°F.

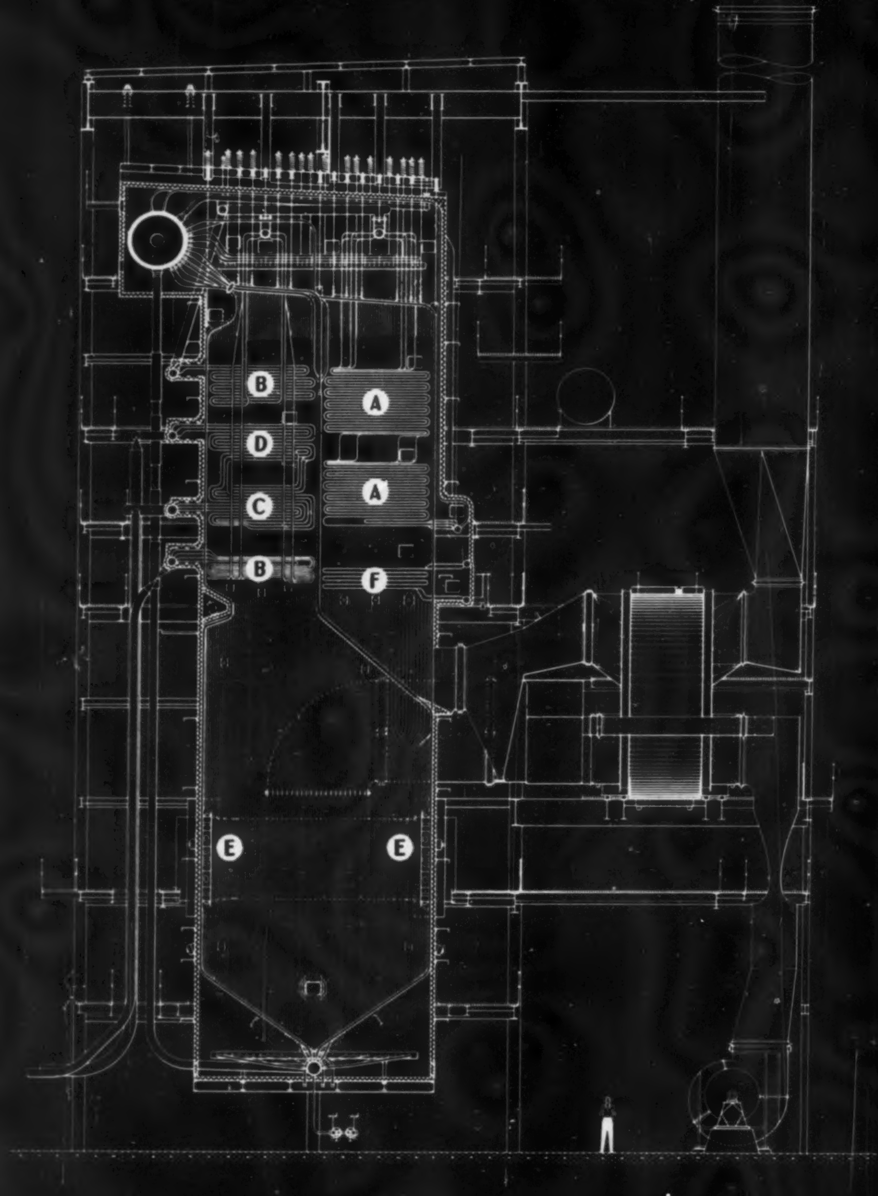


Four Yarway Welbonds on main steam line to turbine at southern power plant. Press. 2310 psi; temp. 1000°F. Over 100 Welbonds here.



Six of 900 Yarway Welbonds at southwest utility. Boiler drum pressure in this plant—2150 psi; superheat temperature 1005°F.

COOL WATER...

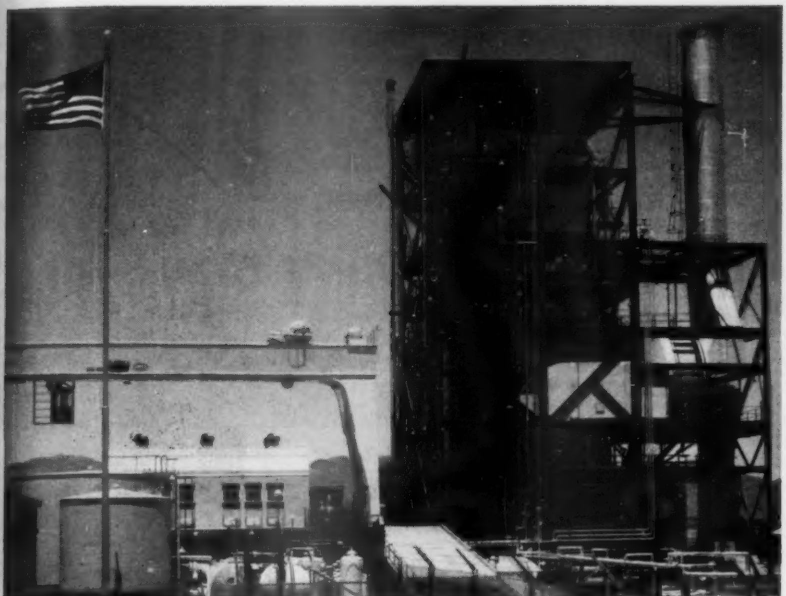


COOL WATER UNIT No. 1

OPERATING DATA:	
Primary Steam Flow	475,000 lb/hr
Design Pressure	2,050 psi
Operating Pressure	1,850 psi
Superheat/Reheat	1,005F/1,005F

KEY TO DRAWING

- A L.T. Superheater Section
- B H.T. Superheater Section
- C H.T. Reheater Section
- D L.T. Reheater Section
- E Tilting Tangential Burners
- F Economizer



New Cool Water Steam Plant goes into service

On June 15th, the first of two steam generating units for California Electric Power Company's new *Cool Water* station went into commercial service.

The 62,000 kw capacity of *Cool Water* Unit No. 1 brings the California Electric system's capability to 484,500 kw. *Cool Water* is served by a C-E steam generator of the radiant, reheat design equipped with tilting tangential burners. It is an outdoor-type unit, fired by natural gas and oil with provision for future pulverized coal firing. Cross-sectional elevation and brief description appear on the opposite page.

Cool Water is located 12 miles east of Barstow, California, on a ranch from which it derives its name. Commercial operation of the unit marks the 68th C-E-equipped *new* utility station to go into service since 1950. ***Consulting engineers: The Fluor Corporation, Ltd., Los Angeles.***

COMBUSTION C-E ENGINEERING

C-331

General Offices: Windsor, Conn.
New York Offices: 200 Madison Avenue, New York 16, N. Y.

NEW UTILITY STATIONS C-E EQUIPPED

Includes only new stations on new sites placed in operation since JANUARY 1, 1950

1. Lake Catherine
2. Hutchison
3. Yates
4. Dunkirk
5. Titus
6. Lee
7. Contra Costa
8. Hawthorn
9. Ninemile Point
10. Edge Moor
11. Palatka
12. Johnsonville
13. Danskammer
14. Beckjord
15. Highgrove
16. Plant X
17. Black Dog
18. Albany
19. Joppa
20. Meramec
21. Portsmouth
22. Lake Creek
23. Etiwanda
24. Aurora
25. Hennepin
26. Eastlake
27. Oak Creek
28. Suwannee River
29. Urquhart
30. Kingston
31. Sandow
32. Mullergren
33. Barry
34. North Omaha
35. Wilmington
36. Carbon
37. Saguaro
38. Morro Bay
39. Vermilion
40. John Sevier
41. Collin
42. Milliken
43. Canaday
44. Gallatin
45. Barrett
46. Mitchell
47. San Bernardino
48. Yorktown
49. Gulf Coast
50. Tucson
51. Port Wentworth
52. W. A. Parish
53. Allen
54. Montrose
55. McMeekin
56. Lewis and Clark
57. Roy S. Nelson
58. Yuma Axis
59. Dickerson
60. Dan E. Karn
61. Willow Glen
62. Ocotillo
63. Darlington County
64. Port Everglades
65. Nichols
66. Eddystone
67. Brunner Island
68. Cool Water

ALL TYPES OF STEAM GENERATING, FUEL BURNING AND RELATED EQUIPMENT; NUCLEAR REACTORS; PAPER MILL EQUIPMENT; PULVERIZERS; FLASH DRYING SYSTEMS; PRESSURE VESSELS; SOIL PIPE

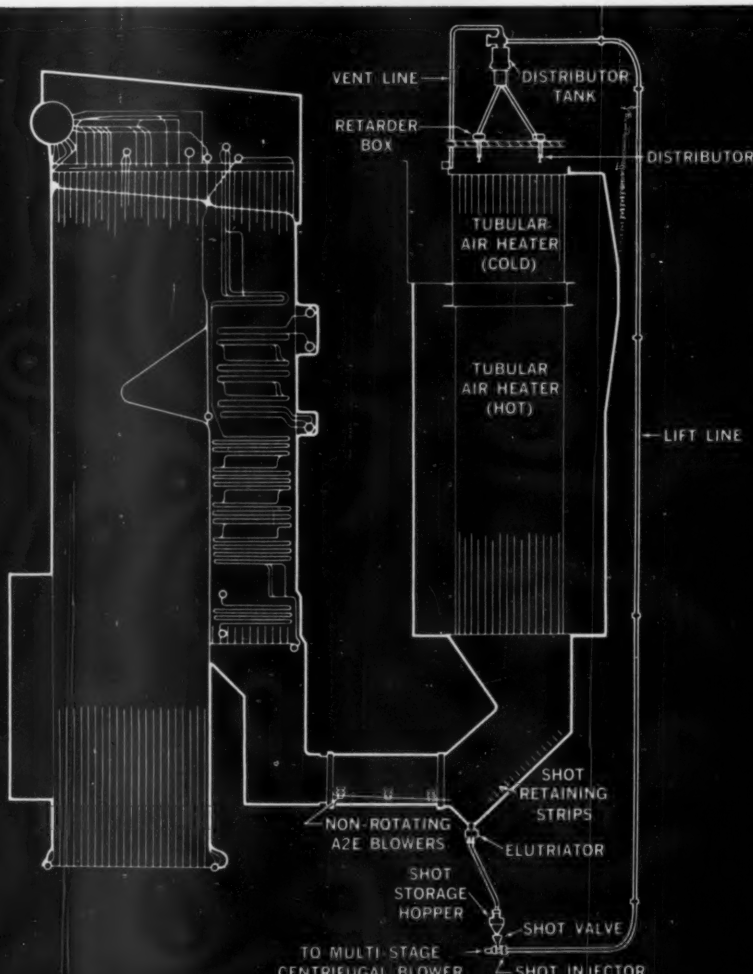
To maintain constantly clean airheaters, thereby minimizing draft losses and reducing annual outage time, Pennsylvania Electric Company is installing Diamond Shot Cleaning Systems on Shawville Station Steam Generating Units No. 1 and 2. Because Diamond Shot Cleaning Systems consistently have proved to be highly effective for this difficult cleaning application, Pennsylvania Electric anticipates significant savings through elimination of unpleasant manual cleaning and the costly boiler downtime that goes with it.

The selection of Diamond Shot Cleaning is typical of Pennsylvania Electric's continuing effort to achieve greater power generating efficiency. It also demonstrates the growing acceptance of a totally new concept in cleaning waste heat, recovery, and power boilers that defy cleaning by conventional methods. At your request, our engineers will be happy to discuss the application of Diamond Shot Cleaning to your new or existing steam generator. Call, write or wire.

DIAMOND POWER

This is the new trademark of Diamond Power ... a symbol of quality, integrity and progress ... in products, systems and service.

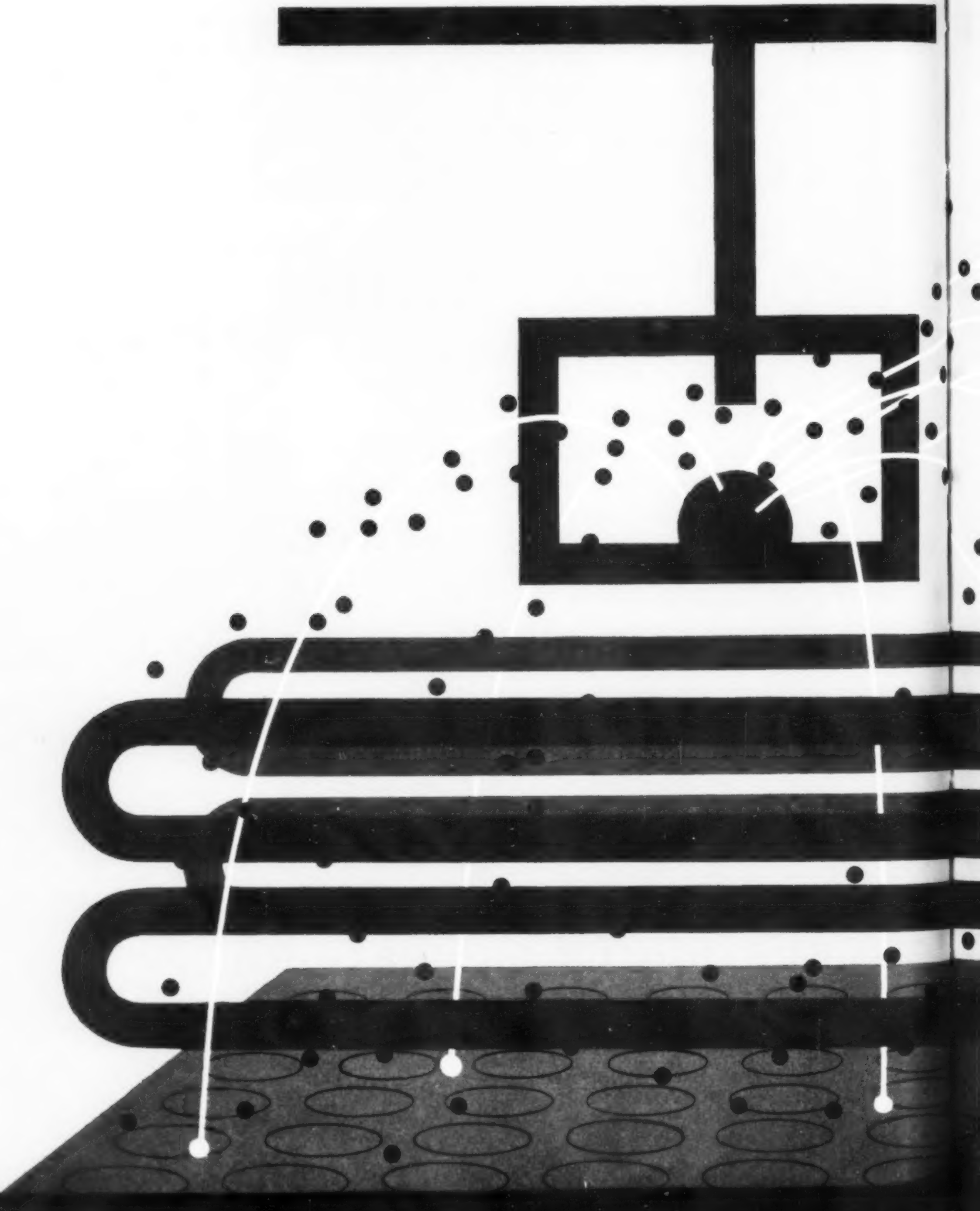
DIAMOND POWER SPECIALTY CORPORATION, Lancaster, Ohio
DIAMOND SPECIALTY LIMITED, Windsor, Ontario



General arrangement of Diamond Shot Cleaning System now being installed on Penna. Electric's Shawville Station Steam Generating Units No. 1 and 2. System has 135 foot lift system . . . highest installation yet using standard equipment.

Diamond developed for more economical power...

PENNSYLVANIA ELECTRIC SELECTS FOR AIR HEATERS THAT WON'T STAY CLEAN!



To maintain constantly clean airheaters, thereby minimizing draft losses and reducing annual outage time, Pennsylvania Electric Company is installing Diamond Shot Cleaning Systems on Shawville Station Steam Generating Units No. 1 and 2. Because Diamond Shot Cleaning Systems consistently have proved to be highly effective for this difficult cleaning application, Pennsylvania Electric anticipates significant savings through elimination of unpleasant manual cleaning and the costly boiler downtime that goes with it.

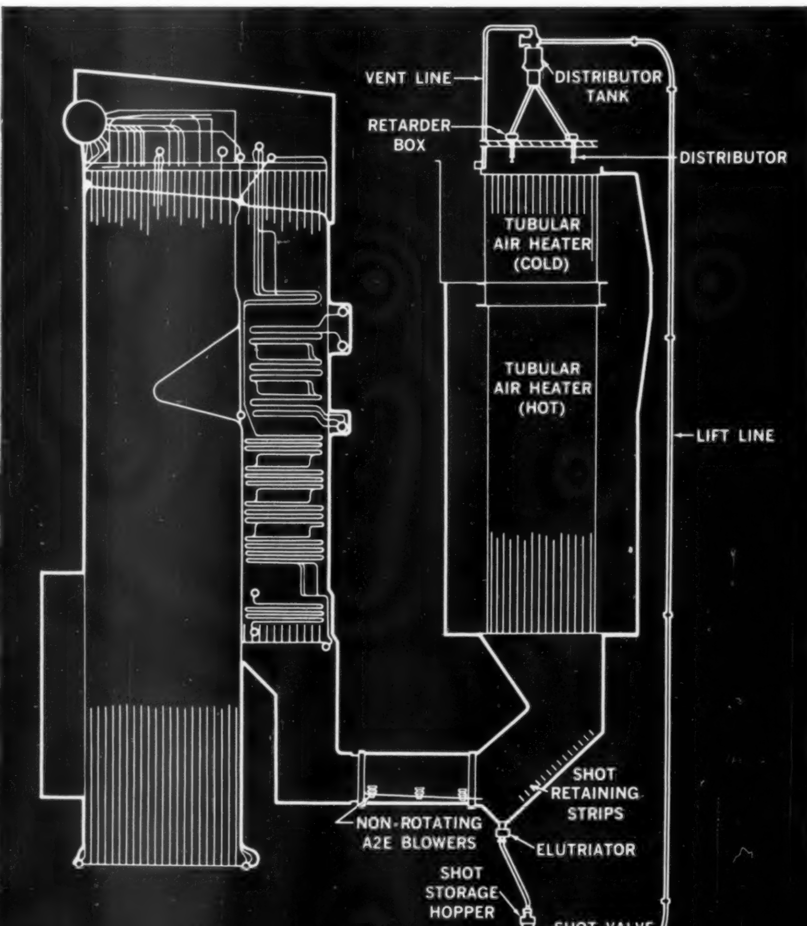
The selection of Diamond Shot Cleaning is typical of Pennsylvania Electric's continuing effort to achieve greater power generating efficiency. It also demonstrates the growing acceptance of a totally new concept in cleaning waste heat, recovery, and power boilers that defy cleaning by conventional methods. At your request, our engineers will be happy to discuss the application of Diamond Shot Cleaning to your new or existing steam generator. Call, write or wire.

DIAMOND POWER

This is the new trademark of Diamond Power . . . a symbol of quality, integrity and progress . . . in products, systems and service.

DIAMOND POWER SPECIALTY CORPORATION, Lancaster, Ohio

DIAMOND SPECIALTY LIMITED, Windsor, Ontario



General arrangement of Diamond Shot Cleaning System now being installed on Penna. Electric's Shawville Station Steam Generating Units No. 1 and 2. System has 135 foot lift system . . . highest installation yet using standard equipment.

187 POUNDS OF ADDITIVE

. . . with every ton of Bell & Zoller coal. What is this "miracle additive"? *Any* one of our combustion engineers. Like a doctor, they're on call 24 hours a day, seven days a week. They can come up with fast, accurate solutions to *your* combustion problems . . . show you how you can get more for each dollar you spend for fuel. All it takes is a phone call from you. Their experience is yours to tap. Take advantage of it. Incidentally, this is our 75th year of business. We're proud of it, but we're even prouder that we're among the top fifteen coal producers in the nation. Our reserve picture is excellent. We'd like to do business with you. And you'll find that you'll like doing business with us!

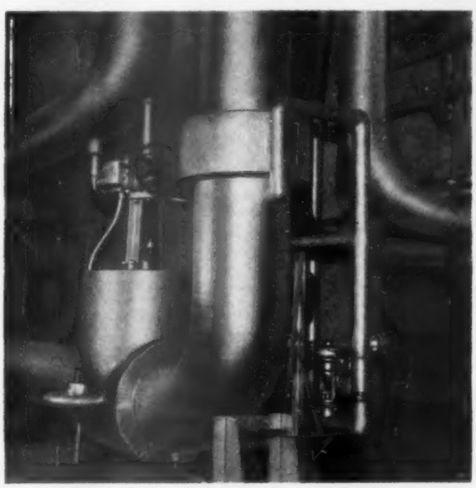
BZ | Bell & Zoller COAL COMPANY

SINCE 1886 | 208 SOUTH LA SALLE STREET, CHICAGO 4, ILLINOIS

ST. LOUIS LOUISVILLE MINNEAPOLIS DECATUR, ILL. OMAHA FOND DU LAC, WIS.

The problem: to maintain the temperature of residual fuel oil at 335°-380°F using station steam at 1250 psig and 950°F. Because of the high temperature heating requirements of the fuel, it was necessary to use the station steam supply. To handle this tough assignment a single, combination pressure-reducing and regulating valve, Copes-Vulcan Type CV-D, followed by the Copes-Vulcan Variable-Orifice desuperheater was used. The cooling-water valve is also a Type CV-D. The desuperheater provides steam at the right temperature to control the fuel oil temperature and viscosity exactly. It has been in service over two years with no downtime and no operating problems.

solves knotty problems at two generating plants



The problem: to deliver 420°F steam at from 20,000 to 300,000 pounds per hour and within ± 5°F of the set point. Conventional desuperheating equipment could not be used because of the low superheat (30°F) and low flow conditions. A 12-inch, 300-psig standard Copes-Vulcan Variable-Orifice desuperheater, with outlet expanded to 20-inch pipe size, was the answer. The inlet is connected with the main steam-distribution header carrying steam at 220 psig and 500°F. The cooling-water supply is at 450 psig and 200°F. The specified pressure range is 425 to 475 psig. Cooling-water flow is automatically regulated by a Copes-Vulcan Type CV-D valve operated by a temperature controller in the steam heating supply line. Flow requirements at discharge temperature within ± 5°F have been met consistently though inlet temperatures vary from 520°F to 550°F.

Copes-Vulcan desuperheaters are designed for precise control of reduced steam temperatures under the most difficult operating conditions.

In addition to the Variable-Orifice, two other types are available. *The Carburetor-Type desuperheater* injects cooling water into the system with a spray nozzle. Available in standard 2-inch through 12-inch sizes in 150- through 600-pound pressure standard for cast steel. Larger sizes and higher pressure standards are available on special application. Write for Bulletin 1056.

Steam-Assist desuperheater has negligible permanent pressure loss on loads of 15% to 100% of maximum. This in-line desuperheater normally uses assisting steam only on light loads where control is most difficult. Write for Bulletin 1024-A. Copes-Vulcan Division, Erie 4, Pennsylvania.

Copes-Vulcan Division

BLAW-KNOX

BLAW-KNOX

Blaw-Knox designs and manufactures for America's growth industries: METALS: Rolling Mills • Steel Processing Lines • Rolls • Castings • Open Hearth Specialties • PROCESSING: Process Design, Engineering and Plant Construction Services • Process Equipment and Pressure Piping • CONSTRUCTION: Concrete and Bituminous Paving Machines • Concrete Batching Plants and Forms • Gratings • AEROSPACE: Fixed and Steerable Antennas • Radio Telescopes • Towers and Special Structures • POWER: Power Plant Specialties and Valves

New Hancock Isolation Valve

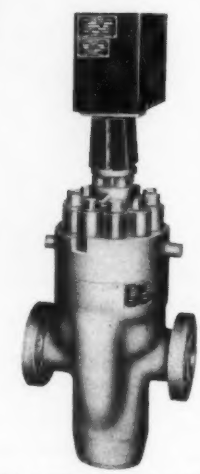
HELPS SIMPLIFY EMERGENCY REPAIRS

Specifically designed to isolate the Consolidated "Electromatic" Relief Valve from the boiler or superheater, this new Hancock Steel Isolation Valve reduces both repair costs and work time by permitting the unit to stay on the line.

Installed under the "Electromatic," the Hancock Isolation Valve utilizes a new type of pressure seal bonnet joint which employs internal system pressure to help provide an extremely tight seal.

The seal ring is not subject to full bonnet load. Seat rings, wedge, and back seating surface are Stellite-faced for long wear. The design is streamlined for clean piping installation. Can be furnished, as illustrated above, with By-Pass Valve to permit equalization of pressure on both sides of the wedge for easier opening.

Complete specification data sent on request. Write today.

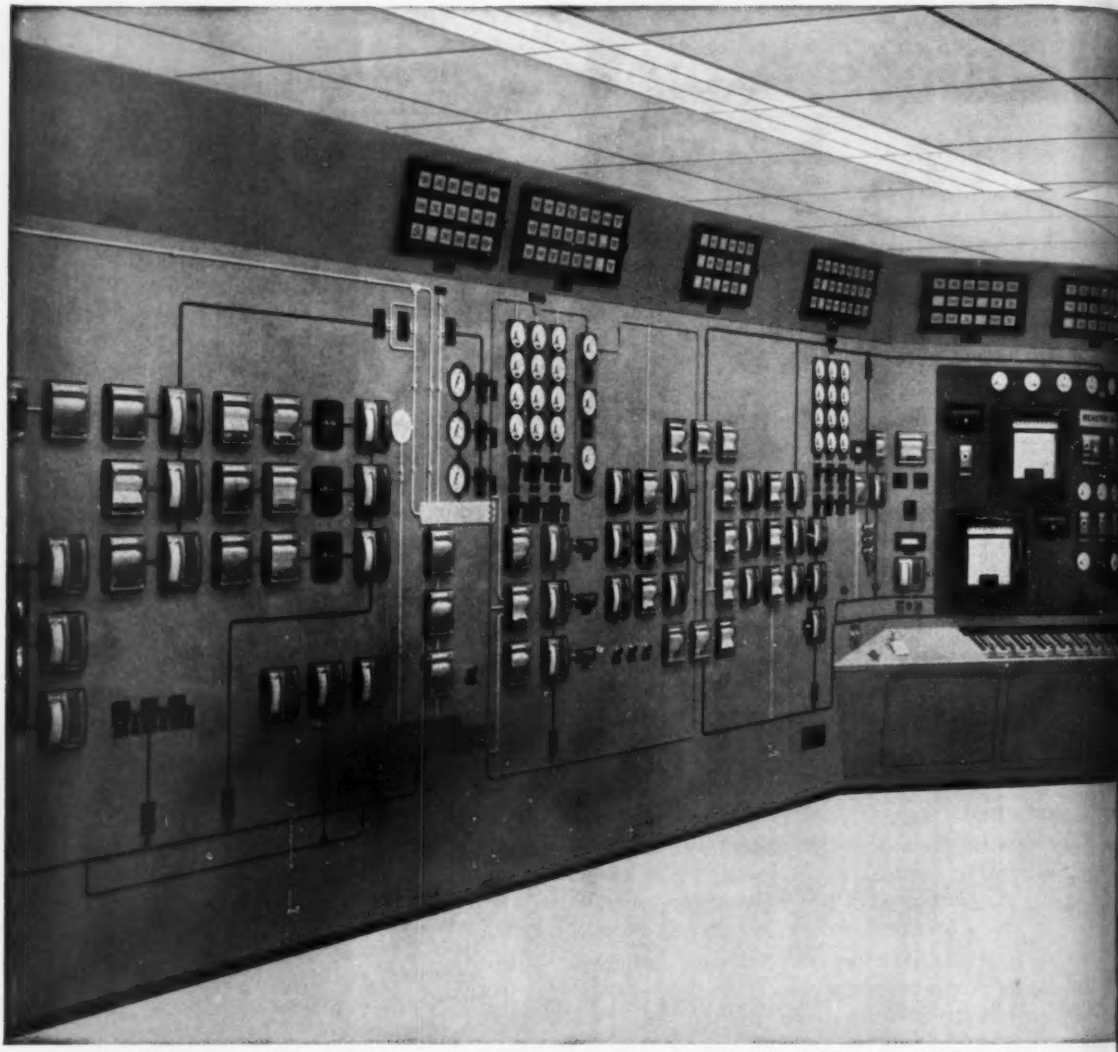


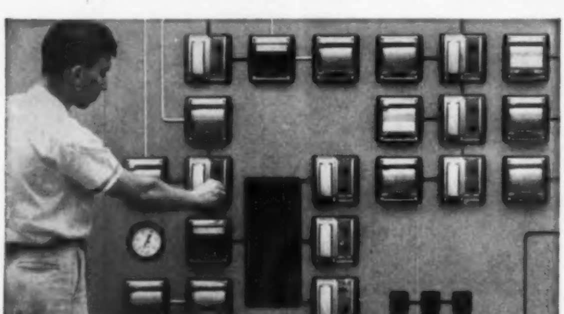
Consolidated "Electromatic" Relief Valve. An automatic electrically-actuated valve that assures accurately balanced boiler operation at peak loads and more uniform line pressure. It saves steam, pure water, fuel, and "wear and tear" on spring-loaded valves. It can also be set to operate before the safety valves and thus becomes the working valve.

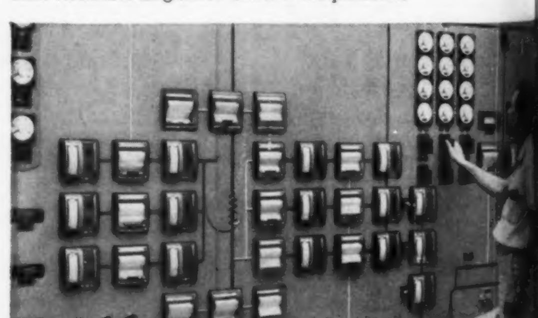
MAXWELL M&M MANNING & MOORE INC TRADE MARK

HANCOCK STEEL VALVES
A product of
MANNING, MAXWELL & MOORE, INC.
Valve Division • Watertown, Massachusetts
Canada: Manning, Maxwell & Moore of Canada, Ltd., Galt, Ontario
Latin America: Export Division, Chrysler Building, New York, N. Y.
Europe: Manning, Maxwell & Moore, S.A., Fribourg, Switzerland

STACK WITH THE MIDAS TOUCH*
MYTHOLOGY: The Midas Touch changed objects into gold.
TECHNOLOGY: This ore smelter goes Midas one better—by extracting gold, silver, copper and zinc from smoke.
Whether recovery or smoke abatement is the objective, depend upon the performance of Koppers Electrostatic Precipitators.
Koppers—a leading manufacturer of gas cleaning equipment for industry.
*Facts available on request
KOPPERS
ELECTROSTATIC PRECIPITATORS
Engineered Products Sold with Service • Baltimore 3, Maryland







specified for new-design reactor

75,000 kw nuclear power plant at Sheldon Station, Hallam, Nebraska controlled by Foxboro

One of America's first sodium-cooled nuclear power plants will soon go critical at the Sheldon Station of Consumer Public Power District of Nebraska. The plant will produce 75,000 kw of electrical power for distribution to the greater Lincoln area.

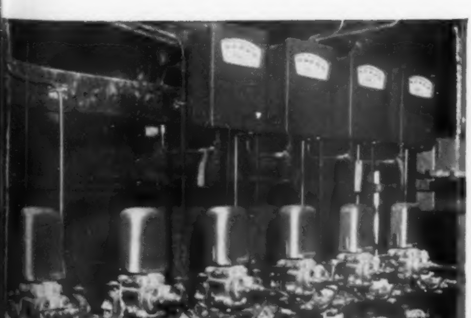
Plant safety, plus exacting performance and reliability requirements, are of critical importance for this advanced power plant. Foxboro instrumentation and Foxboro engineering were chosen for both the heat transfer system and the reactor control system.

For heat transfer cycles, a pneumatic advanced feed-forward control system links master steam pressure control directly to the primary and secondary sodium flow control systems, as well as to the neutron flux control system. Corrections for load changes are immediate — chance of major upset greatly reduced.

Foxboro electronic Consotrol* instruments precisely compute thermal power level and control the systems to maintain constant power — continuously and automatically. Response is instantaneous — and 100% solid-state reliable.

Nuclear and conventional power plants — you can count on Foxboro engineering and instrumentation to match today's most advanced power generating techniques. Ask your nearby Foxboro Field Engineer for full details. Or write The Foxboro Company, 279 Norfolk Street, Foxboro, Massachusetts.

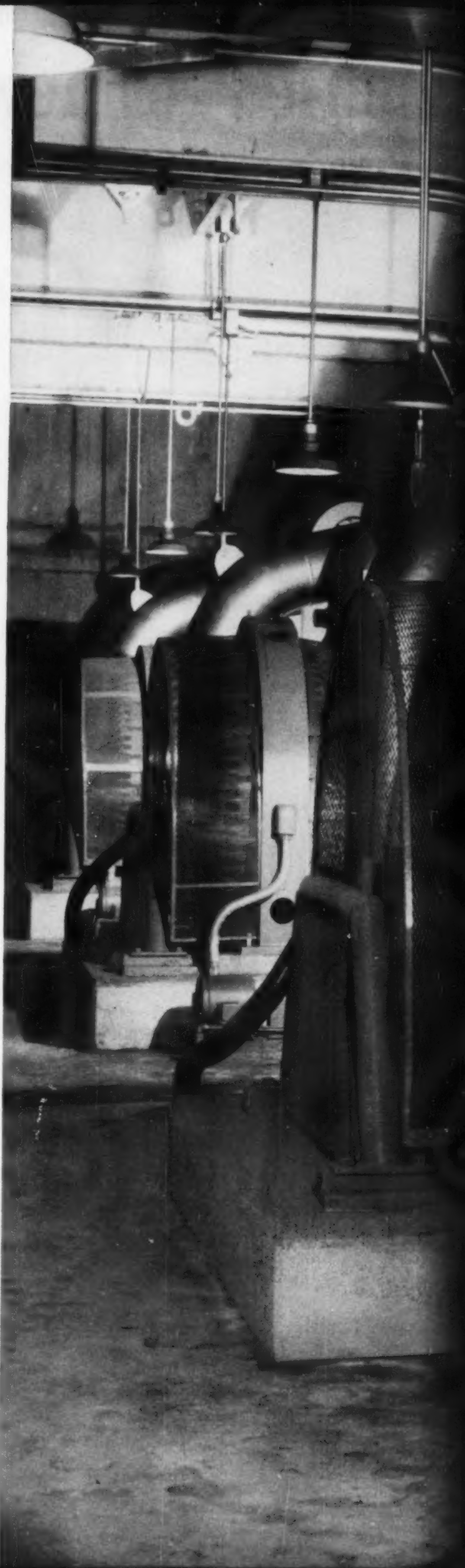
*Reg. U. S. Pat. Off.

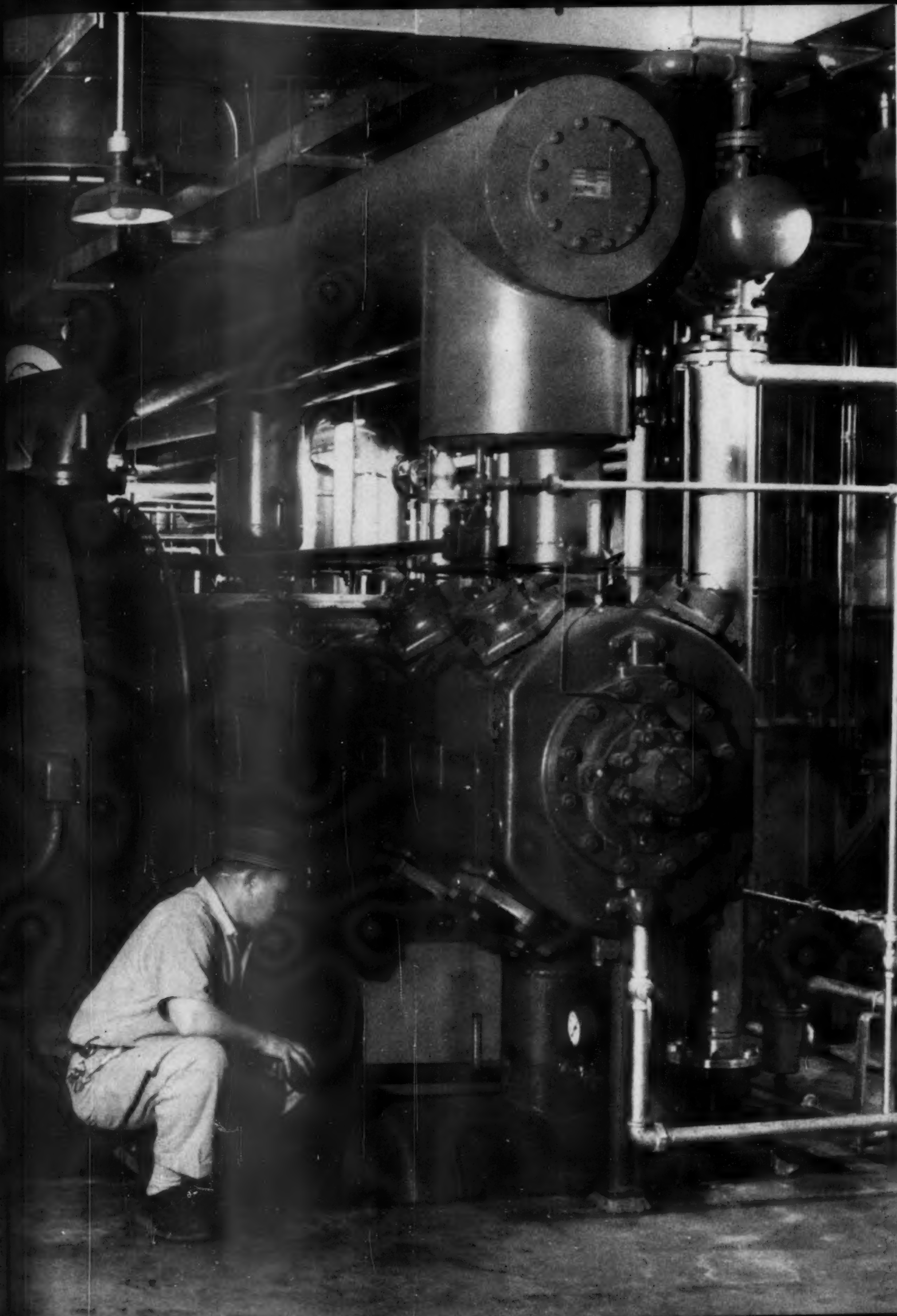


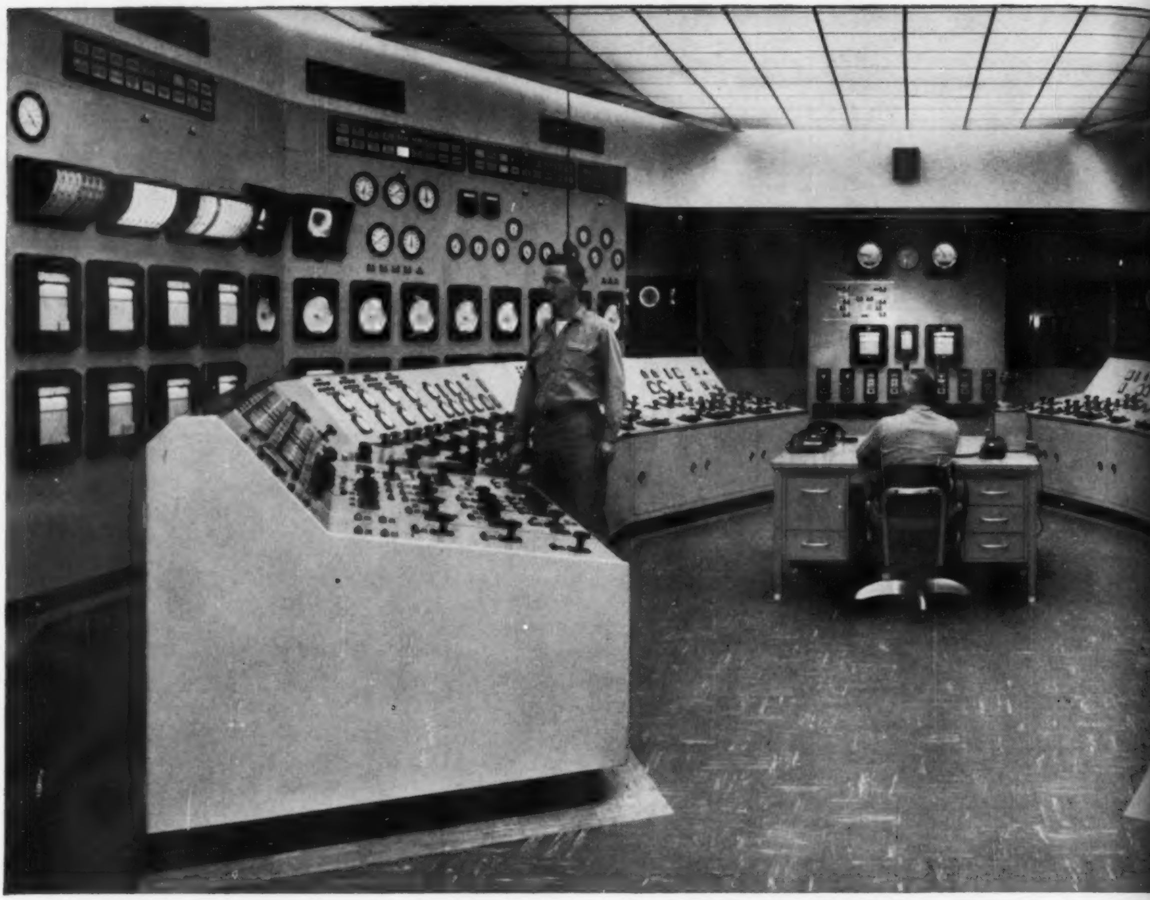
STEAM PRESSURE and flow measurements, plus feed water flow rates, are transmitted pneumatically to main control panel by these Foxboro M/45 Pressure Transmitters and Foxboro d/p Cell* Transmitters.

FOXBORO

REG. U. S. PAT. OFF.





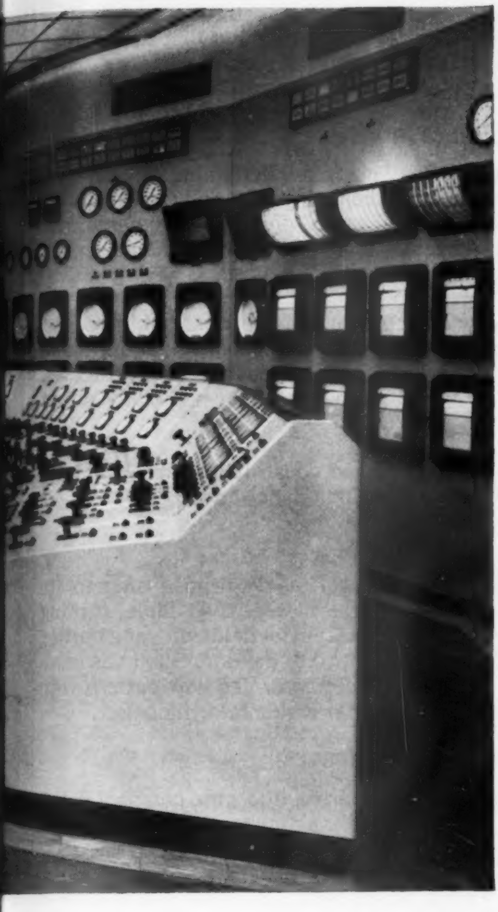


IT'S BAILEY FOR AMERICA'S

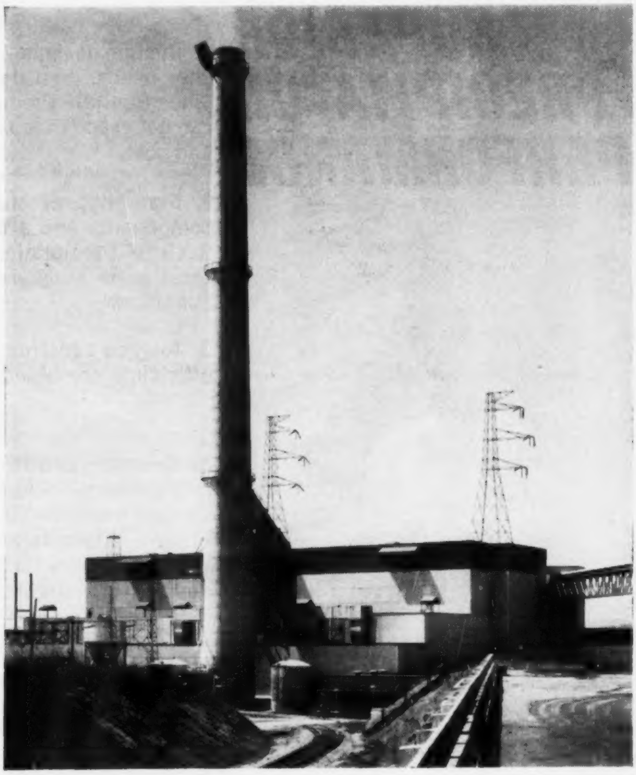
1959 STEAM-ELECTRIC PLANT HEAT RATES FROM FEDERAL POWER COMMISSION REPORT S-143

	Btu/kw-hr	Meters	Combustion Control	Feed Water Control	Superheat Control
1. Dickerson (Potomac Electric Power Co.)	9,007	B	B	B	B
2. Clinch River (Appalachian Power Co.)	9,011	B	—	B	B
3. Kanawha River (Appalachian Power Co.)	9,098	B	B	B	B
4. Silas McMeekin (South Carolina Electric & Gas)	9,130	—	—	—	—
5. Muskingum River (Ohio Power Co.)	9,170	B	B	B	B
6. River Rouge (The Detroit Edison Co.)	9,170	—	—	—	—
7. Clifty Creek (Indiana-Kentucky Electric Corp.)	9,173	B	B	B	B
8. G. G. Allen (Duke Power Co.)	9,174	B	B	B	B
9. Tanners Creek (Indiana & Michigan Electric Co.)	9,176	B	B	B	B
10. Shawville (Pennsylvania Electric Co.)	9,179	B	—	—	B
11. Kammer (Ohio Power Co.)	9,203	B	B	B	B
12. St. Clair (The Detroit Edison Co.)	9,250	B	B	B	B
13. Kyger Creek (Ohio Valley Electric Corp.)	9,284	B	—	B	B
14. Portland (Metropolitan Edison Co.)	9,322	—	—	—	—
15. Oak Creek (Wisconsin Electric Power Co.)	9,336	B	B	B	B
16. Bayshore (Toledo Edison Co.)	9,365	B	B	B	B
17. Milliken (N. Y. State Electric & Gas Corp.)	9,374	B	—	B	—
18. Philip Sporn (Appalachian Power Co.)	9,381	B	B	B	B
19. John Sevier (Tennessee Valley Authority)	9,390	—	—	—	—
20. Mandalay Beach (Southern California Edison Co.)	9,397	B	B	B	B
21. Gallatin (Tennessee Valley Authority)	9,420	—	—	—	—
22. Huntington (Southern California Edison Co.)	9,436	B	B	B	B
23. Colbert (Tennessee Valley Authority)	9,460	B	B	B	B
24. Will County (Commonwealth Edison Co.)	9,460	B	—	B	B
25. Agua Fria (Salt River Project A.I.F. Dist.)	9,473	B	B	B	B
26. Salem Harbor (New England Power Co.)	9,485	B	B	B	B

***per 1959 Heat Rates reported by FPC**



Bailey Controls for combustion, feed water and steam temperatures at the Dickerson Generating Station of Potomac Electric Power Co. The Federal Power Commission reported a 1959 heat rate of 9007 Btu per kw-hr, ranking it as No. 1 plant in efficiency in the United States.



NO. 1* STEAM PLANT

and for 20 out of the next 25 "most efficient" plants, too

Most efficient power plant in 1959, as rated by the Federal Power Commission, was Dickerson Station of Potomac Electric Power Co. And for measuring and controlling functions that helped attain this record, Dickerson relies on Bailey Meters and Controls.

Moreover, *in 21 out of all 26* "most efficient" plants, with heat rates under 9500 Btu per kw-hr, Bailey Meters and Controls are used for some or all functions.

Why? The reasons aren't hard to find. Bailey engineers have worked hand-in-hand with leading power engineers for more than 45 years to advance steam-plant efficiency rates . . . have pioneered the research and development of improved measurement and control techniques that have produced much of today's high reliability of steam-plant operation . . . have simplified and verified instrumentation and control systems to the point where automation can be approached confidently.

And now, working to extend the benefits of automation over the full range of plant operations, Bailey offers systems incorporating advanced techniques for scanning, alarming, logging, computing, digital logic and sequencing . . . all co-ordinated with established analog equipment to provide maximum safety, economy and reliability . . . all compatible with the needs of power management, technical and nontechnical.

Ask your nearby Bailey District Office or Resident Engineer how new Bailey concepts and advanced systems techniques may be applied to your operations.

A-164-2

Instruments, controls, and systems

BAILEY METER COMPANY

1025 IVANHOE ROAD • CLEVELAND 10, OHIO

In Canada—Bailey Meter Company Limited, Montreal

BAILEY METERS

GUEST EDITORIAL

Plain Words

By CAPRICORN

Who is Capricorn?*

Which is the subject that all engineers study but most of them forget; that is precise yet poetic; that is essential to engineering yet can be studied without any reference to engineering? There are no prizes for picking out mathematics.

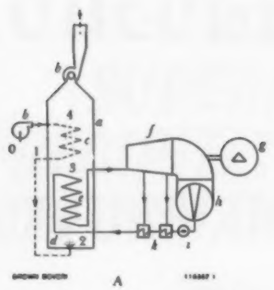
It is the snob subject par excellence. If you don't know the language of mathematics, or even if you have simply forgotten it, you are cut off from the lofty thoughts of those to whom it is familiar symbolism. When the mathematician has expressed a phenomenon in an equation he has the comfortable feeling he understands it fully and finally. In this respect he is almost certainly mistaken, but it gives him a degree of one-upmanship which the non-mathematician cannot hope to demolish. At school, when you plot the height of high tide at the estuary bridge every day for a month, and you produce a beautiful curve, you experience a sense of revelation of the mysteries of the tides. It is only later that you have a greater revelation—that there must be innumerable and unimaginable equations which determine the fall of rainwater in the catchment area, its flow down the river and its meeting with the ungovernable sea—"far back through creeks and inlets making, Comes silent, flooding in, the main." Then, if you have kept your mathematics in trim, you may experience a wild ambition to formulate all those unknown equations.

For mathematics is like golf—it's fun so long as you practice it often enough, but it's hell if you let it go. It allows you to play the great game of "If." Let x equal y, we say, and all sorts of wonderful possibilities flow from such a supposition. The basic mathematical philosophy that however the variables vary, the left-hand side of the equation will still equal the right-hand side, is very attractive in a world where everything is always annoyingly changing. An equation is the constant truth about changeable factors.

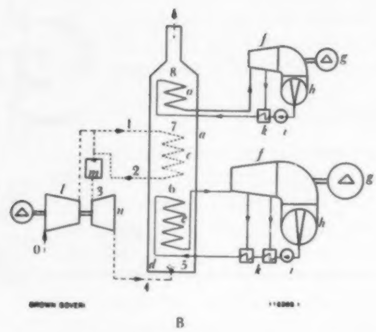
Just as primitive men worshipped the sun, so might we worship mathematics. Most of us could be described as lapsed mathematicians, but we can still revere its power—and get a real mathematician to solve our problems. One of our largest engineering groups is evidently alive to its importance, especially mathematics of the simple sort. The education department of Associated Electrical Industries (Manchester) Limited have produced an admirable brochure describing some visual aids for teaching simple arithmetical, algebraical and geometrical relationships. It is based on some cunning devices which are used in the Siemens and Halske Works school in Berlin. In a foreword to the brochure, Sir Willis Jackson remarks that the devices are easy to construct and that the education department will be pleased to supply further information.

I have half a mind to make them up myself and get back that old black magic.

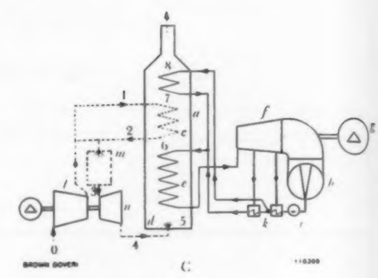
* Capricorn's column appears regularly in the pages of our contemporary, *Engineering*, published in London, England. Diligent research has failed to uncover his identity and *Engineering's* editor, F. B. Roberts, says ". . . he is an imaginary person who, I may say, is more successful than many of us who are real." Capricorn's whimsically pointed remarks continue to delight us—we think you'll enjoy him too. This direct quote of his is from the August 11, 1961 issue.



A: *Plain steam installation* with air heater and bled-steam feedwater heating



B: *Combined installation* with combustion turbine preceding boiler. Heat recovery by autonomous recuperation steam circuit



C: *Combined installation* with preceding combustion turbine. Heat recovery by transfer to part of feedwater

Fig. 1—Running from left to right across this and the facing page as well as the bottom of this one are a number of steam and gas turbine cycles held to be worthy possibilities.

The Theory of Combined Steam and

This article gives a comprehensive and unbiassed survey of the combinations worth considering and derives the basic thermo-dynamic relationships, which determine their mode of operation. These relationships, though quite simple, have not always been correctly analysed.

By C. SEIPPEL

and

R. BEREUTER

Brown-Boveri & Co., Ltd.

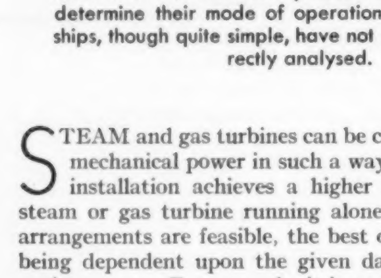
STEAM and gas turbines can be combined to produce mechanical power in such a way that the combined installation achieves a higher efficiency than the steam or gas turbine running alone. Several different arrangements are feasible, the best overall arrangement being dependent upon the given data and the desired performance. For example, it is possible to incorporate a gas-turbine cycle in the combustion circuit of the boiler of a steam system; alternatively a waste-heat boiler and steam turbine can be made to follow a gas turbine. In the first arrangement the main stress is laid on the steam turbine, in the second on the gas turbine.

The primary goal is the attainment of the highest possible thermal efficiency, although this is not solely decisive for the choice of a particular system. The initial outlay and other factors, such as safety, ease of control, fuel properties, number of running hours, and so on, are also quite important. To make any general statements about such factors is, of course, impossible. In the present article the economics of a typical example will be investigated. The remarks apply to installations intended to produce only electricity. The discussion of the special advantages of installations for the simultaneous generation of electricity and process heat was deliberately omitted for the sake of simplicity.

Review of Combined Gas and Steam Turbine Plants

Fig. 1, Fig. 1A, p. 31 and below show a number of layouts, with the aid of which the various possible combinations of gas and steam turbines can be surveyed.

To begin with, diagram A represents a straightforward steam plant. It has been simplified as far as can be permitted for the illustration, but it may be stressed at this point that subsequent considerations will be devoted to all kinds of steam plants, from the simplest to the most complicated. The parts of the steam plant

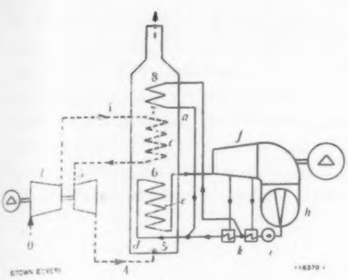


G: *Gas turbine* without preceding steam cycle, but followed by a heat-recovery steam system

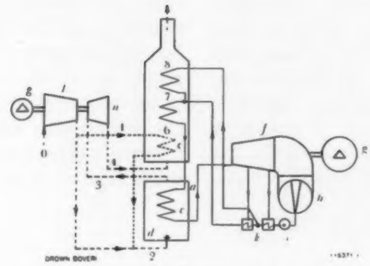
Circuit diagrams of combined steam and gas turbine installations

- - - - Open combustion circuit
—— Closed water-steam circuit

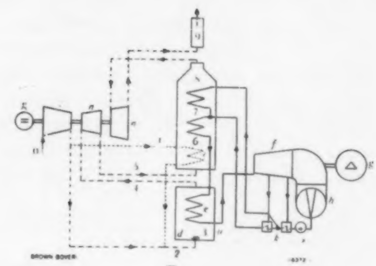
a = Boiler
b = Boiler fans
c = Air heater
d = Combustion chamber with burner
e = Steam part of boiler
f = Steam turbine
g = Generator
h = Condenser
i = Feedwater pump
k = Feedwater heater and de-aerator
l = Compressor
m = Combustion and swirl chamber
n = Gas turbine
o = Autonomous heat-recovery steam circuit



D



E



F

D: *Combined installation* as C, but with air indirectly heated before expansion

E: *Combined installation* with pressure-charged boiler firing (Velox principle)

F: *Combined installation* with pressure-fired boiler, expansion being divided between a hot and a cold stage to reduce the temperature of the exhaust gases

Fig. 1A—Under each of the selected combinations A to G appearing either above or on the facing page are the major identification statistics.

Gas Turbine Installations

which are of interest here are: The boiler *a*, the boiler fans *b*, the air heater *c*, the combustion chamber with at least one burner *d*, the steam section of the boiler—comprising economizer, evaporator, superheater and possibly a reheater—these are indicated in the diagram as a simple through system *e*. Belonging to the turboset are the steam turbine *f*, the generator *g*, the condenser *h*, the feedwater pump *i*, an arbitrary number of feed-water heaters and de-aerating heaters *k*.

In the diagrams *B*, *C* and *D* the boiler is preceded by a gas-turbine set, the exhaust heat of which is utilized in the fire-box of the boiler.

In *B* and *C* air is compressed in a compressor *l* and is heated in a special combustion and swirl chamber *m* to the desired input temperature of the expansion turbine. The air can be heated in an air heater before it flows into the combustion chamber. In the turbine *n*, which drives the compressor, the hot gas gives up power and an appreciable useful output in addition. This gas then enters the fire-box of the boiler and still contains an ample amount of oxygen for combustion. By compression the air is heated by more than 100 deg C. Therefore in the air heater it cannot reduce the temperature of the exhaust gases to the extent possible in *A*. But since the exhaust gases still ought to be cooled to the limit imposed by the dew-point and corrosion, diagram *B* contains an autonomous steam circuit *o* utilizing the waste heat. Instead of this, diagram *C* shows the waste heat being transferred to a leg of the feed-water system, which in many cases renders the air heater superfluous.

In *D* the air is not raised to the temperature required by the expansion turbine by *internal combustion*, but by being heated *externally* in the boiler. However, this necessitates a costly heat exchanger; on the other hand, the expansion turbine operates with clean air. This, so far, is the only possible solution for combined installations in which the fuel has a high ash content, particularly with coal.

Diagram *E* shows a pressure-fired boiler, for instance of the well-known "Velox" type. The Velox boiler belongs to the combined installations as soon as its charging set delivers excess power, which was already the case with early designs of Velox units. The main part of the boiler precedes the gas turbine and operates under pressure. The other part, usually only the economizer, follows the gas turbine.

In diagram *F* the gases are expanded in two stages: a high-pressure stage with high temperatures, and a low-pressure stage with lower temperatures, the object of which is to reduce the temperature of the exhaust gas more than can be done by a heat exchanger. The walls of the latter must be colder than the gases, which is unnecessary in the l.p. turbine.

Finally, diagram *G* shows the important case of a gas turbine with a waste-heat boiler. (*Bottom of p. 30.*)

The systems illustrated in the diagrams permit of certain variants. In *B*, *C*, *E* and *F* the air heater can be left out, which may affect the efficiency, under certain conditions. Moreover, it is permissible to dispense with recuperation in *B*, provided one is willing to accept a drop in efficiency. The air can also be compressed in several stages with intercoolers and the gas expanded in several stages with reheating.

At this point one problem warrants special attention. Combined installations, such as in *B* and *C* for instance, have a pair of combustion chambers in series. The second operates with air containing a reduced amount of oxygen, but at a high temperature, so that combustion does not present any difficulties. On the other hand, with gas or oil firing, it is possible, in the event of a misfire in one of the combustion chambers, for the flame to flash over explosively from the other. The installation must consequently be built in such a way that this cannot cause any damage.

Two-stage combustion has been thoroughly tested with gas turbines and has proved reliable. Both combustion chambers are explosion-proof.

The idea of harnessing gas and steam turbines together

is by no means new. Stodola (1)[1] discussed utilization of waste heat in a steam circuit in 1922, while in 1936 Schröder (2) drew up the main boiler connections with gas turbines. Numerous patents, many of which would not stand up to a novelty search, though, describe different variants. It is therefore logical to ask why more combined plants have not been built, if this is the case. Doubtless this is partly due to a dislike of complication in operation. It was feared that new sources of trouble could be introduced into the installation. It is considered right to think of a combined gas and steam plant when this does not involve any more complications, either as regards operation or maintenance, than the boiler fans which it replaces. By adhering to the wealth of experience gained with gas turbines and charging sets, it may be claimed this goal has been attained.

Thermodynamics of Combined Steam and Gas Turbine Plants

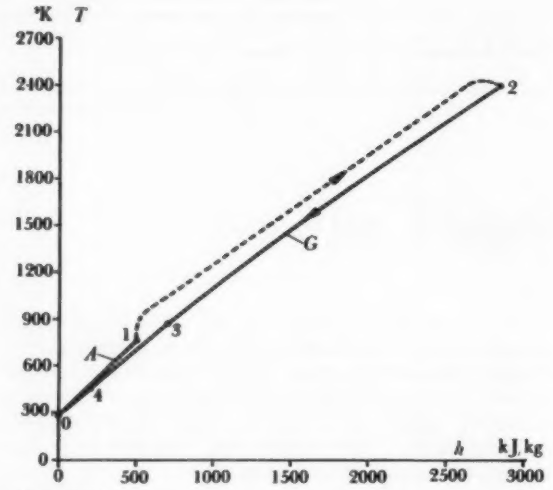


Fig. 2—Temperature—enthalpy diagram $T = f(h)$

In the diagram at the left letter A stands for Air, G for gas. The diagram represents the conditions for Case A Fig. 1, p 30 and Table I below

TABLE I—STRAIGHTFORWARD STEAM BOILER

Positions on Diagram, Fig. 2	States in the Combustion Circuit	Enthalpy Flow Referred to 1 kg Air Per Second
0–1	Air heating	Q_0 (+)
1–2	Combustion	
	Introduced as fuel with calorific value H_0	
	Remaining after subtraction of losses due to radiation and unburnt fuel	$\eta_H H_0$ (+)
2–3	Heat given up to steam circuit	V_0 (−)
3–4	Heat given up to air heater	Q_0 (−)
4–0	Heat lost up the chimney	Z_0 (−)

A. STEAM PLANT WITH A GAS TURBINE IN THE COMBUSTION CIRCUIT

STARTING with a steam plant as in diagram *A*, the first question to be investigated was, under what circumstances and by how much the efficiency could be improved by inserting a gas turbine in the combustion circuit, as shown in *B*.

1. The Energy Balances

a. Straightforward steam plant, diagram A of Fig. 1, p. 30

For the combustion air and combustion gases Fig. 2 shows the relationship between temperature and enthalpy, referred to the enthalpy at the ambient temperature. Plotted in this curve are the successive states in the combustion circuit.

In view of the complicated diagrams which follow, Fig. 2 has been unfolded and a method of representation chosen, by which the changes in energy in the combustion circuit can be placed successively, regardless of their sign. The latter can be seen from the droop or rise of the temperature curve, as well as from a special portion of the curve below the axis. (Fig. 3 which, in contrast to Fig. 2, is not to scale.)

b. Combined plant, diagram B of Fig. 1. p. 30

Fig. 4 shows the successive states in the combustion circuit. From the Tables I above and II, the following energy balances are obtained:

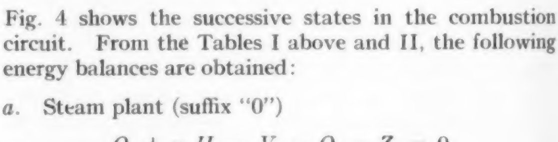
a. Steam plant (suffix "0")

$$Q_0 + \eta_H H_0 - V_0 - Q_0 - Z_0 = 0$$

or, solved for the heat absorbed by the steam

$$V_0 = \eta_H H_0 - Z_0 \qquad (1)$$

b. Combined plant (without suffix) . . . . . next page . . . .



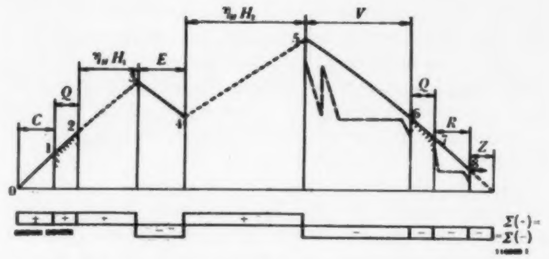
(Dotted line below solid line V. represents steam states in the boiler).

Fig. 3—Unfolded temperature—enthalpy diagram $T = f(h)$ for air and combustion gas according to system A

[1] The figures in parentheses refer to the bibliography at the close of the article.

TABLE II—COMBINED CYCLE

Positions on Diagram, Fig. 4	States in the Combustion Circuit	Enthalpy Flow Referred to 1 kg Air Per Second
0–1	Compression	$C(+)$
1–2	Air heating	$Q(+)$
2–3	First combustion stage	$\eta_H H_1(+)$
3–4	Expansion	$E(-)$
4–5	Second combustion stage	$\eta_H H_2(+)$
5–6	Heat given up to steam circuit	$V(-)$
6–7	Heat transferred to air	$Q(-)$
7–8	Heat-recovery stage (recuperation)	$R(-)$
8–0	Heat lost up the chimney	$Z(-)$



Dotted lines below solid line V are high pressure steam states in the boiler. Dotted below R are low pressure steam states in heat recovery circuit.

Fig. 4—Temperature—enthalpy diagram $T = f(h)$ for air and combustion gas according to system B

$$C + Q + \eta_H H_1 - E + \eta_H H_2 - V - Q - R - Z = 0$$

or, solved for the heat absorbed by the steam

$$V = \eta_H(H_1 + H_2) - Z - (E - C) - R \qquad (2)$$

The outputs of the two plants are

a. $$P_0 = \eta_{th} V_0 - P_{0,\,aux} \quad \text{where:} \qquad (3)$$

η_{th} = the thermal efficiency of the steam turbine referred to the terminal output, less the power consumed by the drives of the feedwater and cooling-water pumps, and heat V_0 absorbed by the steam.

$P_{0,\,aux}$ = the power consumed by the auxiliaries, excepting the feedwater and cooling-water pumps.[2]

b. $$P = \eta_{el}(E - C) + \eta_{th} V + \eta_R R - P_{aux} \qquad (4)$$

in which:

η_{el} = the efficiency of the generator gas-turbine set

η_R = the thermal efficiency of the utilization of the waste heat (recuperation efficiency)

[2] Strictly speaking, it should be borne in mind that some of the heat coming from the auxiliaries is utilized by the boiler and must therefore be taken into account in the heat and energy balances. For the sake of simplicity the recovered heat is subtracted from the power of the auxiliaries, so that P_{aux} denotes the net amount.

Comparisons of Plant A with Plant B

Let us now compare the two plants, assuming an air throughput of 1 kg/s and the following conditions:

(i) The pressure and temperature of the live steam—and if necessary of the reheated steam—and the vacuum and feedwater temperatures are equal in both cases. The internal efficiency of the steam turbine, the feedwater and cooling-water pumps, and the quality of the feed-heaters and generator are also equal in both cases, and hence the thermal efficiency of the steam turbine. This most important, and also logical, assumption naturally only applies to the hp steam circuit in *B*, but not for any recuperation circuit (top of diagram *B*), the steam data in which are limited by the gas temperature.

(ii) The fuel input is also assumed to be equal and to correspond to the smallest possible excess of air

$$H_1 + H_2 = H_0$$

On page 37 the conditions are shown under which this assumption is justified.

(iii) The exhaust-gas temperature is assumed to be equal in both cases, and thus the exhaust gas loss too.

$$Z = Z_0$$

(iv) Power of the auxiliaries: The power for the auxiliary pumps of the steam turbine, especially the feedwater and cooling-water pumps, was taken into account in η_{th} and was thus made proportional to the output of the steam turbine, which is reasonably accurate. The remaining auxiliary power is mainly consumed by the boiler fans in *A*, which are omitted in *B*. Instead the gas turbine operates with a back pressure which overcomes the boiler resistance, thereby reducing the gas turbine output. In the calculation we omit these two approximately equal terms, so that the auxiliary power can be expressed as $P_{aux} = P_{0,\,aux}$.

Under these assumptions the equation for the flow of energy (2) may be written

$$V = \eta H_0 - Z_0 - (E - C) - R$$

or, allowing for (1),

$$V = V_0 - (E - C) - R \qquad (2a)$$

and the power equation (4)

$$P = \eta_{el}(E - C) + \eta_{th}[(V_0 - (E - C) - R] + \eta_R R - P_{aux} \qquad (4a)$$

If we now subtract equation (3) from this, the gain in output per kg/s of air becomes

$$P - P_0 = (\eta_{el} - \eta_{th})(E - C) - (\eta_{th} - \eta_R)R \qquad (5)$$

Since equal heat input was assumed, the percentage improvement in the thermal efficiency of the installation, referred to that of the steam plant is

$$\frac{\Delta\eta}{\eta_0} = \frac{P - P_0}{P_0} = (\eta_{el} - \eta_{th})\frac{E - C}{P_0} - (\eta_{th} - \eta_R)\frac{R}{P_0} \qquad (6)$$

The expression (5) consists of a first, positive, additive term corresponding to the output of the gas-turbine set $\eta_{el}(E - C)$ from which $\eta_{th}(E - C)$ must be subtracted,

because the amount of heat $(E - C)$ is obtained from the gas, and thus not available for the steam cycle. It contains a second, negative term, namely—$(\eta_{th} - \eta_R)R$, originating from the residual heat R which performs work with a poorer recuperation efficiency η_R than if it had been utilized in the hp steam circuit with η_{th} via the air heater.

With the aid of equation (6) it is possible to calculate the improvement effected by combining a gas turbine with a steam plant. First the recuperation power R and the efficiency of recuperation η_R must be studied more closely; later the expressions for E and C, and their optimization are dealt with.

2. The Recuperation Power R

In the straightforward steam plant the exhaust gases at the air inlet to the preheater are considerably hotter than the incoming air. The enthalpy of the exhaust gases, referred to the ambient temperature (Fig. 5a) is higher by the amount of the exhaust-gas losses Z_0. In the combined installation the air is already heated to a temperature T_1 by compression before it enters the heater. It is often warmer than the exhaust gas leaving the steam plant. Consequently the gas temperature at the outlet from the air heater has to be increased, in order that the heat may be transferred with a sufficient temperature difference. An obvious solution is to dispense with the part of the heater in which the air is heated to T_1 in the ordinary steam plant, and to retain the rest of the heater unchanged. It heats the air with the same temperature difference between gas and air, and attains the same final temperature as before (Fig. 5b). In this case the loss of the transferred amount of heat corresponds exactly to the work of compression. This heat is supplied by the recuperator and is given by

$$R = C \tag{7}$$

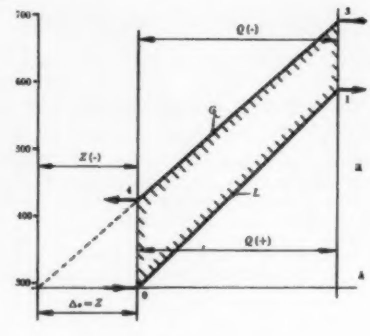
But there are often reasons for deviating from this law, as follows:

(a) Reduction of the temperature difference between air and gas in the air heater. In the steam plant this is defined, on the one hand by the atmospheric temperature and, on the other, by the lowest temperature to which the exhaust gases may be cooled without moisture condensing and giving rise to such difficulties as corrosion. In the combined plant the temperature difference may be lowered so long as this is advantageous for the efficiency, which should be rated higher than the extra costs for the heat exchanger. The enthalpy difference per second between gas and air is then, as may be seen from Fig. 5c, no longer Z_0 but Δ, which is $<Z_0$. In this case the recuperation power is

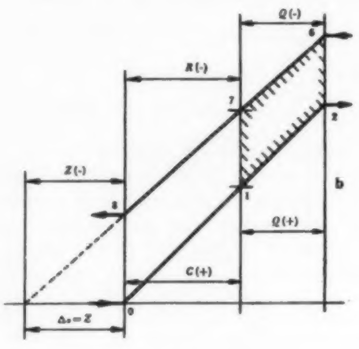
$$R = C - (Z - \Delta) \tag{8}$$

(b) Here a remark concerning the ordinary steam plant is called for. Also, with such installations, the temperature difference in the air heater, which is indeed the cause of thermodynamic losses, can be reduced by pre-heating the air by low-pressure bled steam before it is conveyed to the flue-gas heat exchanger. The thermal efficiency can thus be improved.

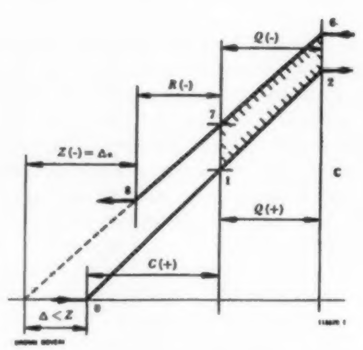
(c) Sometimes the recuperation power is increased above the value C, in order to dispense completely with the air heater (1–2 in diagram B).



5(a) Recuperation $R = O$ (System A)



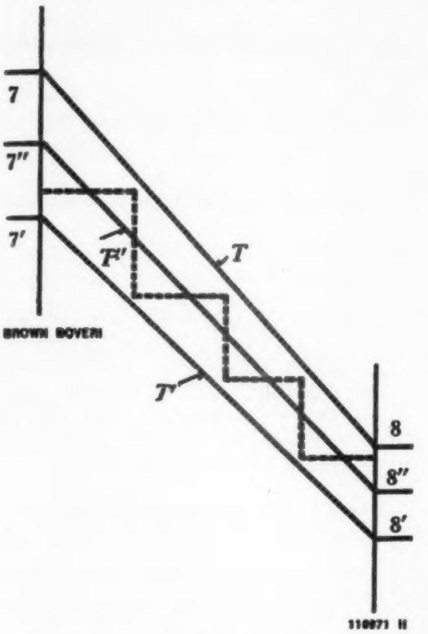
5(b) Recuperation $R = C$ (System B)



5(c) Recuperation $R = C - (Z - \Delta)$ (System B)

Fig. 5—Temperature—enthalpy diagram $T = f(h)$ for the air heater

(d) Instead of utilizing the heat in a waste-heat boiler with a special turbine, as in B, it can be used to heat the feedwater for the main turbine, as in C. Then it is advantageous for the feedwater flow to be divided after it passes the lower feed-heating stages. One part flows through the upper feed-heating stages, the rest through the waste-heat boiler. This is feasible since the "hydraulic coefficient" of the current of water—the product of the specific heat and the mass flow—is greater than that of the gas current. Diagram C shows this variant. Here the air heater is shown dotted because in most cases it may well be dispensed with.



T = *Temperature of exhaust gases*
T′ = *Temperature of feedwater*
T″ = *Temperature of bled steam*

Fig. 6—Temperature—enthalpy diagram $T = f(h)$ in the recuperator and bled-steam feedwater heaters

Fig. 6 shows the temperatures in the recuperation system. The gas current is cooled from T_7 to T_8, while the portion of the feedwater current is heated from T'_8 to T'_7. The slope of the line $T'_7 - T'_8$ depends on the ratio in which the feedwater current is divided. It could be made parallel to the gas line $T_7 - T_8$. It is still better to make T' proportional to T, which is not only simple as regards calculation, but gives an optimum thermodynamic result.[3]

When an air heater is provided (diagrams *C* and *D*), T_7 is determined, as before, by the compression temperature and the temperature difference in the air heater. In this case

$$R = C - (Z - \Delta)$$

Care must be taken to ensure that the feedwater temperature T'_7 agrees with the final temperature of the bled-steam heating—or of any intermediate stage—and if it does not, the ratio in which the water is divided must be changed, dispensing with the exact proportionality of T and T'.

If the flue-gas is not used to preheat the air, T_7 is determined by the final temperature T'_7 of the feedwater and the temperature difference of the heat transfer from flue-gas to feedwater. In this case

$$R = (h_7 - h_8)\dot{m}_E \qquad (9)$$

in which $h_{7,\,8}$ are the enthalpies and $\dot{m}_E$ the mass flow of the flue-gases.

3. The Recuperation Efficiency

Of the heat to be recuperated R, only the portion η_c is available to do work, according to Carnot's law, i.e.

$$\eta_c = \frac{1}{R}\int_{T_8}^{T_7}\left((1 - \frac{T_0}{T}\right) \mathrm{d}R = 1 - \frac{\log_e T_7/T_8}{T_7 - T_8} \,.\, T_0 \qquad (10)$$

owing to the linear relationship between R and T, in which T = gas temperature; T_0 = ambient temperature (i.e., of cooling water).

The heat must be transferred to a working medium such as a stream circuit, as indicated in Fig. 4 by the dotted lines. The three sections of the line represent feed-heating, evaporation and superheating. The useful part of the heat contained in the steam, i.e., the "cycle efficiency," is given by

$$\eta_{Pr} = \frac{\Delta H - T_0 \cdot \Delta s}{\Delta h} \qquad (11)$$

where Δh and Δs represent the enthalpy $\int \mathrm{d}Q$ and entropy $\int dQ/T'$ absorbed by the steam generator. Since the temperature T' in the steam circuit is lower than T in the gas,

$$\eta_{Pr} < \eta_c$$

The usable energy in the steam is utilized at the "thermodynamic" efficiency of the turbine η_{td}, which takes into account the losses in the turbine and generator, the power used to drive the feed pump and irreversibility of the feed-heating system and condenser.

Hence

$$\eta_R = \eta_{Pr} \cdot \eta_{td} \qquad (12)$$

Winning energy from heat carriers at not unduly high temperatures was comprehensively studied for atomic power plants. Reference may be made to article (3) in the bibliography, which gives the fundamental theory for the design of a recuperation system. The recuperation efficiency η_R can be read directly off Fig. 6 of that article.

When the recuperated heat is transferred to the feedwater as in *C* and *D*, the output of the turbine

---

[3] Proof of this statement:

A quantity of heat Q is to be transferred from a medium with a given temperature distribution T to another medium with a temperature T' which can be chosen freely. T' must be such that, for a given transfer area and overall heat transmission coefficient k, the increase in entropy is a minimum.

The heat transfer area is

$$A = \frac{1}{k}\int_0^Q \frac{\mathrm{d}Q}{T - T'},$$

and the increase in entropy

$$s = \int_0^Q \left(\frac{1}{T'} - \frac{1}{T}\right) \mathrm{d}Q$$

We now have to find the function (T') which minimizes the integral

$$I = \int_0^Q \left[\left(\frac{1}{T'} - \frac{1}{T}\right) + \lambda \cdot \frac{1}{T - T'}\right] \cdot \mathrm{d}Q = \int_0^Q F(T')\mathrm{d}Q$$

λ being an arbitrary multiplier. The Euler equation of the variation calculus in this case is

$$\frac{\partial F}{\partial T'} = 0 \text{ and gives } -\frac{1}{T'^2} + \frac{\lambda}{(T - T')^2} = 0$$

or $\dfrac{T - T'}{T'} = \sqrt{\lambda}$, i.e., T' is proportional to T.

can be equated to the two amounts of heat applied to the circuit per second, namely $V = V' + V''$ and R:

$$P = \eta_{th}(V' + V'') + \eta_R R$$

where:

R = recuperated power from the exhaust-gas temperature to the temperature corresponding to the highest bleed point

V'' = power recuperated above the temperature determined by the highest bleed point. Hence V'' is applied to the whole of the feedwater and can thus be added to the boiler

$\eta_R R$ can be determined as follows: T_7, T_8, T'_7 and T'_8 (Fig. 6) are stipulated, T_8 being the given final temperature of the gas, T'_7 the given final temperature of the feedwater; T_7 and T'_8 are given by the selected temperature differences of the preheater. Then R and the ratio of the division of the feedwater have to be determined, and the bleeding quantities taken from the thermal diagram of the turbine, in particular those quantities which would have been required to heat the diverted feedwater. The gain in output resulting from its remaining in the turbine can also be determined from the thermal diagram.

For general investigations, in which the flow diagram of the plant is not exactly stipulated, the following procedure may be adopted: the stepped curve for the temperature of the bled steam (Fig. 6) is replaced by a straight line T''_7 and T''_8. The available percentage of the enthalpy of the bled steam is then

$$\eta''_c = 1 - \frac{\log_e T''_7/T''_8}{T''_7 - T''_8} \cdot T_0$$

This is converted at the "hydraulic efficiency" of the turbine, and therefore

$$\eta_R = \left(1 - \frac{\log_e T''_7/T''_8}{T''_7 - T''_8} \cdot T_0\right) \eta_{hydr}$$

If proportional temperatures are also chosen, substituting

$$\begin{aligned} T' &= (1 - \delta')\, T \\ T'' &= (1 + \delta'')\, T' \end{aligned} \tag{13}$$

we obtain

$$\eta_R = \left[1 - \frac{1}{(1 - \delta')(1 + \delta'')} \cdot \frac{\log_e T_7/T_8}{T_7 - T_8} \cdot T_0\right]\eta_{hydr} \tag{14}$$

in which η_R, as desired, is expressed in terms of T_7 and T_8.

4. The Output of the Gas-Turbine Set and the Choice of its Working Pressure

The compression and expansion powers C and E per kg/s of air are calculated with the aid of the following equations, the suffixes 0 and 1 referring to the stagnation conditions before and after the compressor blading, 3 and 4 before and after the turbine blading (diagrams C and D).

$$C = c_{pc} \cdot (T_1 - T_0) \tag{15}$$

$$T_1 = T_0 \pi^{a_c} \tag{15a}$$

where $\pi = p_1/p_0$ compression ratio.

$$\alpha_c = \left[\frac{R}{c_p}\right]_c \cdot \frac{1}{\eta_c} \text{ polytropic exponent of the compression} \tag{15b}$$

where:

η_c = polytropic efficiency of the compressor blading

R = gas constant

$$E = \frac{\dot m_E}{\dot m_c} \cdot c_{pE} \cdot (T_3 - T_4) \tag{16}$$

$$T_4 = T_3(\epsilon\pi)^{-a_E} \tag{16a}$$

where $\epsilon\pi = p_3/p_4$, the pressure ratio on expansion

$$\epsilon = \Pi\,(1 - \delta p/p)$$

or

$\log_e \epsilon = -\Sigma\delta p/p$, in which $\Sigma\delta p/p$ is the sum of all pressure drop ratios in the inlet and outlet pipes of the machines, piping, combustion chambers, heat exchangers—and, under the appropriate conditions, less the resistance on the gas side of the boiler (as a result of assumption (iv))

$$a_E = \left[\frac{R}{c_p}\right]_E \cdot \eta_E \text{ polytropic exponent of expansion} \tag{16b}$$

η_E = polytropic efficiency of the turbine blading

$\dot m_c$, $\dot m_E$ = mass flow through compressor and turbine, respectively. The mass flow of the gas is greater than that of the air by the fuel input, and less than it by the leakage.[4]

With the aid of equation (5) an attempt will now be made to obtain the compression ratio π which yields the maximum power gain and, in consequence of the constant heat input, the maximum efficiency.

The equation (5) has to be differentiated and equated to zero.

$$d(P - P_0) = d[(\eta_{el} - \eta_{th}) \cdot (E - C) - (\eta_{th} - \eta_R) \cdot R] = 0$$

In this we must distinguish between the variation and non-variation of the recuperation energy R with changes in π. This is so when this energy is fed into an autonomous steam circuit, likewise when the gas temperature at the inlet to the recuperator is governed by a preceding flue-gas air heater, and the latter influences the choice of the bleed points. In contrast R is invariable when the temperature is only prescribed by the final temperature of the feedwater (E and F, Fig. 1). This simple case is hereby assumed. From the above equation there remains

$$d(E - C) = 0$$

The most favorable gas turbine is the one with the maximum output per kg air per second, and not the one with the maximum efficiency.

With the aid of equations (15) and (16) we obtain

$$d(E - C) = -c_{pc} \cdot dT_1 - \frac{\dot m_E}{\dot m_c} \cdot c_{pE} \cdot dT_4 =$$

$$c_{pc} \cdot a_c \cdot T_1 \cdot \frac{d\pi}{\pi} + \frac{\dot m_E}{\dot m_c} \cdot c_{pE} \cdot a_E \cdot T_4 \cdot \frac{d\pi}{\pi} = 0$$

or with

[4] The above equations apply for constant specific heat during compression and expansion. For general considerations this may be held to be admissible. For binding guarantee calculations it is essential to work with exact gas tables.

$$\eta_G \equiv \frac{\dot{m}_E}{\dot{m}_c} \cdot \frac{c_{pE}}{c_{pc}} \cdot \frac{a_E}{a_c} = \frac{\dot{m}_E}{\dot{m}_c} \cdot \frac{R_E}{R_c} \cdot \eta_c \cdot \eta_E$$

$$T_1 = \eta_G \cdot T_4 \tag{17}$$

Since the inlet temperatures T_0, T_3 are generally given, we may substitute

$$\pi^{(a_c+a_E)} = \frac{\eta_G}{\epsilon^{a_E}} \cdot \frac{T_3}{T_0} \tag{18}$$

with the aid of (15a) and (16a). If, on the other hand, R is variable, then η_R will also be variable. It is convenient to introduce the marginal value $\eta_{R\cdot mg}$ of η_R, which originates from the degree of utilization of the last element of input heat dR. This occurs at the highest temperature T_7. Hence its Carnot fraction is $1 - T_0/T_7$ instead of

$$1 - \frac{\log_e T_7/T_8}{T_7 - T_8} \cdot T_0$$

so that, to a first approximation, $\eta_{R\cdot mg}$ and η_R may be substituted in this proportion. According to the definition of the marginal efficiency

$$\mathrm{d}(\eta_R R) \equiv \eta_{R\cdot mg} \cdot \mathrm{d}R$$

From (7) or (8) we obtain dR = dC; while, according to (17) and (18)

$$T_1 = \left(\frac{\eta_{el} - \eta_{th}}{\eta_{el} - \eta_{R\cdot mg}}\right) \cdot \eta_G \cdot T_4 \tag{17a}$$

$$\pi^{(a_c+a_E)} = \left(\frac{\eta_{el} - \eta_{th}}{\eta_{el} - \eta_{R\cdot mg}}\right) \cdot \frac{\eta_G}{\epsilon^{a_E}} \cdot \frac{T_3}{T_0} \tag{18a}$$

When evaluating this equation it must be borne in mind that π is implicitly included in $\eta_{R\cdot mg}$.

In the realization of an installation it is, of course, not necessary to adhere strictly to the optimum working pressure. The price and controllability of the machines may give rise to modifications which, provided they are not unduly large, only cause quite small drops in the efficiency, which can be tolerated as such. However, the efficiency at optimum pressure should always be regarded as a measure of what can be attained.

B. GAS TURBINES WITH HEAT RECOVERY

1. First let us consider as a gas turbine without any subsequent combustion, i.e., a straightforward gas turbine with heat recovery (diagram G). The stipulation of constant fuel input, as laid down on page 33, is dispensed with in this case.

In the heat balance (2) we assume $V = 0$ and $H_2 = 0$.

$$\eta_H H_1 - Z - (E - C) - R = 0$$

or, with equation (8): $R = C - (Z - \Delta)$

$$\eta_H H_1 = E + \Delta$$

The output is

$$P_1 = \eta_{el}(E - C) + \eta_R R - P_{aux}$$

and the efficiency

$$\eta_{GT} \equiv \frac{P_1}{H_1} = \frac{\eta_{el}(E - C) + \eta_R R - P_{aux}}{1/\eta_H (E + \Delta)} \tag{19}$$

2. In the second combustion chamber (diagram B) the fuel energy H_2 which can be increased from 0 to $H_0 - H_1$, is added. In the steam turbine the amount $\eta_{th}\eta_H H_2$ is produced in addition.[5]

The efficiency of the combined installation—with variable amount of excess air—is given by

$$\eta = \frac{P_1 + \eta_{th}\eta_H H_2}{H_1 + H_2} = \frac{\eta_{GT} H_1 + \eta_{th}\eta_H H_2}{H}$$

or

$$\eta - \eta_{GT} = (\eta_{th}\eta_H - \eta_{GT})\frac{H_2}{H} \tag{20}$$

The H_2 part of the steam plant is only advantageous when

$$\eta_{th}\eta_H > \eta_{GT}$$

Equation (20) shows that H_2 must be made as large as possible, provided $\eta_{th}\eta_H$ is greater than η_{GT}. This implies that, as for the plain steam cycle, an effort should be made to execute combustion with the smallest possible amount of excess air. The stipulation $H_1 + H_2 = H_0$ on page 33 is thus justified. If, on the other hand, $\eta_{th}\eta_H$ is smaller than η_{GT}, it is preferable to substitute $H_2 = 0$, i.e., the second combustion stage is dispensed with altogether. A solution between these extremes, i.e., where only part of the available oxygen is utilized in the second combustion chamber, never brings any advantage, as far as the efficiency is concerned. It is nevertheless selected sometimes, when the relationship of the gas turbine output to that of the steam turbine has to be shifted, either for economic reasons or to obtain full benefit from an existing gas or steam turbine.

The results of investigations which have been carried out may be summarized as follows:

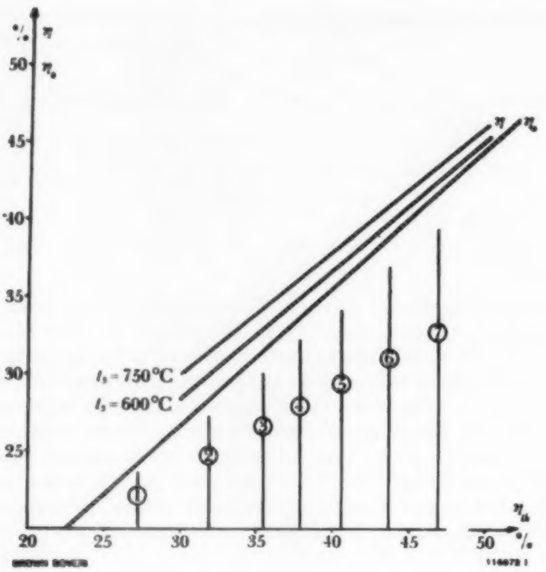
(a) The superiority of a *combined installation over a plain steam plant* is given by equations (5) and (6). Let us introduce the term

$$\eta_{GT}^{*} = \frac{\eta_{el}(E - C) + \eta_R R}{E} \tag{21}$$

In the numerator is the output of a gas turbine with heat recovery, in the denominator the work of expansion, which would be equal to the heat input to a gas turbine with a perfect heat exchanger and without any losses in the combustion chamber. If this ideal gas turbine efficiency were substituted in (5), the gain in efficiency could be expressed in the following simple form:

$$\eta - \eta_0 = (\eta_{GT}^{*} - \eta_{th})\frac{E}{H} \tag{22}$$

[5] Simultaneously the final air heating temperature can be changed and the ratio of the first to the second fuel input shifted, without changing the efficiency of the installation. This might be necessary if the gas temperature in the h.p. boiler were not sufficiently high to realize the desired steam cycle. It must then be remembered that, in subsequent equations, H_1 and H_2 are no longer the fuel heat inputs to the combustion chambers, but that H_1 is the heat needed by the gas-turbine cycle alone, and H_2 the surplus above it.



① St. Andrä, Austria
② Tuncbilek, Turkey
③ Donington, Great Britain
④ Fortuna III, Germany
⑤ Philip Spron, USA
⑥ River Rouge, USA
⑦ Eddystone, USA

Fig. 7—Efficiency of a steam plant η_0 and combined steam-gas turbine installation η according to system D, in terms of the thermal efficiency η_{th} of the steam turbine at two values of t_3, the inlet temperature for the gas turbine

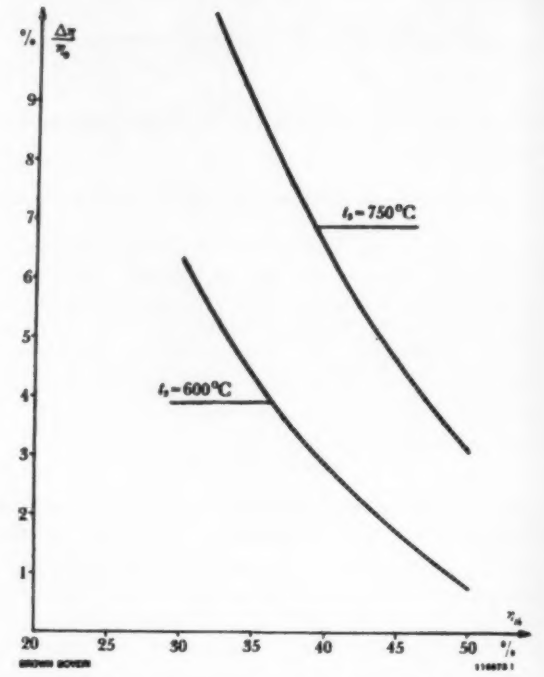


Fig. 8—Multiplicative improvement in efficiency $\Delta\eta/\eta_0$ as a function of the thermal efficiency of the steam turbine ηth for combined steam-gas turbine installations in accordance with system D, at two values of t_3, the inlet temperature to the gas turbine

(b) The superiority of a *combined plant over a plain gas turbine with heat recovery* may be expressed equally simply if we introduce a further "ideal" gas turbine efficiency, defined by

$$\eta_{GT}^{**} = \eta_{GT}/\eta_H$$

This corresponds to the efficiency of the gas turbine with heat recovery, referred to the actual heat input to the gas, i.e., without combustion chamber losses.

$$\eta - \eta_{GT} = (\eta_{th} - \eta_{GT}^{**}) \frac{\eta_H H_2}{H} \qquad (23)$$

(c) From the last two equations we may derive the following criteria for the installation with the best efficiency.

$\eta_{th} > \eta_{GT}^{*}$ plain steam plant

$\eta_{GT}^{*} > \eta_{th} > \eta_{GT}^{**}$ combined plant with additional combustion

$\eta_{GT}^{**} > \eta_{th}$ gas turbine with heat recovery, but without additional combustion

The combined installation with additional heating is thus only advantageous when the thermal efficiency of the steam cycle η_{th} is between the limits η_{GT}^{*} and η_{GT}^{**}.

C. RESULTS, OTHER CIRCUIT ARRANGEMENTS AND CONTROL SYSTEMS

Fig. 7 shows the efficiency of a straightforward steam installation η_0 and that of a combined steam and gas plant η for a temperature of 600 and 750 C before the gas turbine in terms of thermal efficiency η_{th} of the steam turbine. The η_{th} values of a number of existing steam plants are also plotted (4). From this illustration it can be seen that an improvement of $\Delta\eta = \eta - \eta_0$ can always be achieved with the combined installation. The multiplicative improvement $\Delta\eta/\eta_0$ decreases with increasing η_{th}, as may be seen in Fig. 8, drawn to an enlarged scale. With higher temperatures at the inlet to the gas turbine the improvement is correspondingly greater.

If, in a gas-turbine set, the air is compressed in several say n stages with intercooling, and expansion takes place in m stages with reheating, it is no longer permissible to use the equations (18) and (18a) for π. But for such cases it is possible to derive appropriate equations.

Since numerical investigations of systems including intercooling, even with recovery of the dissipated heat in a partial feedwater current, so far resulted in deterioration of the efficiency and since, on the other hand, the gain with reheating was very modest and only obtainable under definite conditions, we believe that such combinations are not interesting for the conventional gas turbine inlet temperatures. Present remarks are therefore confined to giving three more, simple equations which can be used in such cases, without going into their complicated derivation and application. The optimum total compression ratio for variable R and η_R is given by

$$\pi\left(\frac{a_c}{n} + \frac{a_E}{m}\right) = \frac{(\eta_{el} - \eta_{th})\,\eta_G\,[T_{3f}]_j}{\epsilon^{a_E/m}[(\eta_{el} - \eta_{R.\,mgt})\,T_{0t}]_i} \qquad (24)$$

where

$$i = 1, 2 \cdots n$$
$$j = 1, 2 \cdots m$$

and $[\ ]_i$ or $[\ ]_j$ denote the geometric mean, for example for i the n-th root of the product of n quantities.

The individual optimum compression and expansion ratios are

$$\frac{\pi_i}{\pi^{1/n}} = \left\{\frac{[(\eta_{el} - \eta_{th})\ T_{0i}]_i}{(\eta_{el} - \eta_{R\cdot mgi})\ T_{0i}}\right\}^{1/a_c} \tag{25}$$

$$\frac{\pi_i}{(\epsilon\pi)^{1/m}} = \left\{\frac{T_{3j}}{[T_{3j}]}\right\}^{1/a_E} \tag{26}$$

If, however, R and η_R are constant, the terms $(n_{el} - \eta_{th})$ and $(\eta_{el} - \eta_{R\cdot mgi})$ in (24) and (25) become equal to 1. Equation (26), however, remains unchanged.

The typical example given below deals with the behaviour of the set at full load. Should there be any importance attached to partial load, this demands exhaustive investigation, which can only be outlined here. For variable load the following alternatives would, for instance, have to be considered: 1. Bypass combustion chamber, 2. Split-shaft gas turbine, 3. Gas-turbine set designed for the principal load point, and generation of overload output by supplementary fans for the boiler.

Example of a Typical Economic Investigation

Primarily we are interested in learning which of the systems A to G is the most economical. In this case one variant, namely B, can be eliminated straight away; it was merely introduced for fundamental reasons but is obviously a good deal more expensive than C, besides having a poorer efficiency.

System F can only be recommended in preference to E in special cases. Admittedly it offers a proved thermodynamic advantage, but this is quite insignificant. If a plant is only intended to supply heat and no electricity, or if, for any reasons, such as for control purposes, as much as possible of the power gain is to be obtained from the steam turbine and as little as possible from the gas turbine, system F will be adopted. Moreover, this system shows that, owing to the heat pump effect of the gas turbine, it should be possible in principle to attain a thermal efficiency of a boiler of over 100 per cent, a statement which some years ago was, quite wrongly, received with grave disapproval in the technical press.

Compared with C (without air heater), system G is rather at a disadvantage from the efficiency aspect with the chosen steam cycle, but nevertheless very interesting in situations where, for other reasons, a gas turbine is employed as the main machine.

In the following remarks only the systems A, C, D and E without air heater will be compared with one another. The installations were first calculated thermodynamically with oil as the fuel and the prices estimated as accurately as possible in the limited amount of time available for this investigation. In order to obtain approximate prices without too much work, the following assumptions were made, which, to a certain extent, were due to the fact that the investigation uses data for a project ready for execution.

1. For all four systems the same total steam-turbine output is assumed, including the auxiliaries and generator. This yields constant costs for the steam turbine and boiler, and thus for the entire steam plant.
2. Consequent upon the choice of fuel, the mixing temperature before the gas turbine for systems C to E was fixed at 600 C. The pressure ratio was made optimum for each cycle.
3. Atmospheric temperature assumed to be 15 C.
4. Stipulated cooling-water temperature 10 C.
5. Temperature of the exhaust gases 150 C.
6. For A, C and D the efficiency allowing for boiler radiation and unburnt fuel was assumed to be 97 per cent, but in E was made 98 per cent, because in that

TABLE III—COMPONENT ENERGY CONSUMPTION

Scheme			A	C	D	E without Air Heater
Heat input per s from fuel	H	kw	179,000	189,000	186,000	188,000
Efficiency after radiation, including incomplete combustion	η_H		0.97	0.97	0.97	0.98
Heat transferred per s to steam	$\eta_H H$	kw	173,000	183,000	181,000	184,000
Absorbed by the steam circuit	$V' + V''$	kw	162,000	153,000	156,000	155,000
Absorbed by recuperation	R	kw	...	11,600	8,000	8,800
Output of steam turbine with V''	$n_{th}(V' + V'')$	kw	68,300	64,700	65,800	65,600
Power gained by recuperation	$\eta_R R$	kw	...	3,630	2,470	2,720
Total steam turbine output	P_{ST}	kw	68,300	68,300	68,300	68,300
Gas turbine output	$n_{el}(E - C)$	kw	...	6,800	6,100	8,400
Loss due to boiler fans, less gain in steam cycle	ΔP_{fan}	kw	380	...	...	...
Reduction in gas turbine output due to expansion to boiler or recuperator inlet pressure, less gain in steam cycle	ΔP_{GT}	kw	...	450	960	340
Gas turbine auxiliaries	P_{aux}	kw	...	200	200	200
Net output of the whole plant	P	kw	67,900	74,500	73,200	76,200
Quantity of live steam		kg/s	54.6	51.9	52.4	52.2
Feedwater temperature before boiler		°C	212	212	238	246
Optimum compression ratio		π_{opt}	...	~5.2	5.5	6.0
Efficiencies and improvements in per cent						
Efficiency of the plain steam plant		η_0	38.1	38.1	38.1	38.5
Improvement in efficiency		$\Delta\eta$	...	1.14	0.87	1.92
Percentage improvement on η_0		$\Delta\eta/\eta_0$	...	3.0	2.3	5.0
Overall efficiency of the combined installation		η	38.1	39.2	39.0	40.4

TABLE IV—AIR HEATER CRITERIA AND COSTS

Scheme	A	C	D		E without Air Heater
Air temperature before heater, deg C	17	214	211		...
Air temperature after heater, deg C	248	300	600		...
Gas temperature before air heater, deg C	350	350	650		...
Gas temperature after air heater, deg C	150	275	315		...
Air mass flow in air heater, kg/s	76.2	80.6	79.4		...
Gas mass flow in air heater, kg/s	80.5	85.2	84.0		...
Specific heat of air in air heater, kJ/kg deg C	1.014	1.036	1.071		...
Specific heat of gas in air heater, kJ/kg deg C	1.106	1.125	1.176		...
Heat transferred per unit time P_{AH}, kw	17,800	7220	33,100		...
			Ferritic	Austenitic	
Mean temperature difference gas-air Δt_m, deg C	119	55	83	56	...
$kF = P/_{AH}\Delta t_m$, kw/deg C	150	130	305	145	...
Total pressure drop in air heater, per cent	3.6	3.6	3.6	11.9	...
Price ratio air heater/steam plant, per cent	1.5	1.3	3.0	10.8	...
Overall price ratio air heater/steam plant, per cent	1.5	1.3	13.8		...

TABLE V—RECUPERATOR CRITERIA AND COSTS

Scheme	A	C	D		E without Air Heater	
			R	*V''*	*R*	*V''*
Water temperature before recuperator, deg C	...	123	123	212	123	212
Water temperature after recuperator, deg C	...	212	212	238	212	246
Gas temperature before recuperator, deg C	...	275	244	315	244	334
Gas temperature after recuperator, deg C	...	150	150	244	150	244
Water mass flow in recuperator, kg/s	...	29.6	20.5	52.4	22.2	52.2
Gas mass flow in recuperator, kg/s	...	85.2	84.0	84.0	84.7	84.7
Water mass flow heated by bled steam, kg/s	54.6	22.3	31.9	...	30.0	...
Total water mass flow, kg/s	54.6	51.9	52.4	52.4	52.2	52.2
Heat transferred per unit time P_{rec}, kw	...	11,600	8010	6300	8800	8400
Mean temperature difference, Δt_m, deg C	...	41.7	29.4	51.2	29.4	55.4
$kF = P_{rec}/\Delta t_m$, kw/deg C	...	278	272	123	300	152
Pressure drop on air side of recuperator, per cent	...	3.9	2.2	1.7	2.0	1.9
Price ratio recuperator/steam plant, per cent	...	3.2	3.1	1.4	3.5	1.7
Overall price ratio recuperator/steam plant, per cent	...	3.2	4.5		5.2	

case the boiler is much smaller.

7. Electrical efficiency of the generator driven by the gas turbine 98 per cent.

8. In accordance with the theory developed, combustion is as complete as possible in all cases, assuming an air surplus of 20 per cent.

9. The installations were all based on the following steam-turbine data:

Live-steam pressure.................130 kg/cm² abs
Live-steam temperature.....................530 C
Reheating temperature.....................525 C
Pressure in condenser................0.0265 kg/cm²
7-stage bleeding for feedwater heating
Thermal efficiency of the steam turbine. 42.2 per cent

The price differences *C-A*, *D-A* and *E-A* were worked out. They are due to the gas-turbine set, the changed air heaters and feedwater heaters, the extra recuperators and, particularly in E, to the pressure-charged boiler. From the constant price of the steam plant, as per assumption 1, and the price differences, we can obtain the total price for the installation by summation. At the same time the net output of the complete installation was worked out for the various alternatives, and of course is not the same for all systems. But this fact is reflected in the cost of the installation per kw output. For the individual systems the following flows of energy per s are obtained in kw (Table III).

Table IV shows the data of the air heater with approximate prices referred to the price of the entire steam plant (less building and erection), which was made 100 per cent.

In the above it is striking that in system *D*, the air heater has to have a ferritic and an austenitic section, owing to the high temperature, and this naturally increases its price.

Table V shows the data of the recuperators with price estimates, again referred to the price of the entire steam plant, less building and erection.

Thus all the information has been tabulated, from which the total prices of the installations and the cost of the installation per kw net output can be calculated.

Discussion of the results can be kept quite brief. *From the Tables it follows that system E without air heater is by far the most favorable variant.* Not only is the improvement in efficiency of this installation highest, but the specific price per kw is also most favorable. The latter is mainly due to the boiler being pressure-charged which, according to latest investigations, implies that appreciable savings in weight and price may be anticipated.

Without mentioning particularly any of the data in this article, the following results may be gained from the investigations. Comparison of the four systems also works out in favour of *E* for other fuels, such as natural gas or blast-furnace gas. This conclusion ought also to apply for coke-oven gas, although this has not been investigated in detail. For systems burning only coal it is only feasible to employ system *A* or *D*, the former being obviously preferable from the price aspect.

If several fuels have to be used, the installations

TABLE VI—PRICE COMPARISONS

Scheme	A	C	D	E without Air Heater
Complete steam turboset, per cent	38.5			
Boiler, per cent	30.8			
Piping, feedwater pumps, water treatment plant, cooling plant, per cent	9.6	as A	as A	as A
Electrical auxiliaries, switchgear, per cent	17.3			
Miscellaneous, per cent	3.8			
Complete steam plant, excluding building and erection work, per cent	100.0	100.0	100.0	100.0
Price differences compared with A				
Gas turboset, per cent	...	+ 11.3	+ 11.3	+ 11.4
Air heater, per cent	...	− 0.2	+ 12.3	− 1.5
Recuperator, per cent	...	+ 3.2	+ 4.6	+ 5.2
Bled-steam feed-heating, per cent	...	− 0.6	− 0.4	− 0.4
Boiler, per cent	...	...	...	− 11.9
Electrical equipment and piping, per cent	...	+ 3.7	+ 3.5	+ 3.8
Total price difference, per cent	...	+ 17.4	+ 31.3	+ 6.5
Total price of whole installation excluding building and erection work, per cent	100.0	117.4	131.3	106.5
Installation price per kw net output, per cent	100.0	107.0	122.0	95.0

naturally become more complicated, although liquid and gaseous fuels can both be burned in plants of system E. If coal is added to these, it will be better to adopt system A and connect it in parallel with E on the steam side.

In conclusion, we would like to express our conviction in the promising future which lies ahead of combined installations with pressure-charged boilers followed by gas turbines. It is firmly believed that, in the long run, these installations will conquer the field in which liquid and gaseous fuels are employed.

BIBLIOGRAPHY

(1) A. Stodola: Dampf- und Gasturbinen. 5th edition, 1922, pp. 984 and 995. Springer-Verlag, Berlin.

(2) K. Schröder: Der innere Ausbau von Kraftwerken. Die Wärme. 1936, Vol. 59, No. 9, pp. 158–61.

(3) C. E. Lundgren, C. Seippel: Thermal Problems of Atomic Power Stations (II). *Brown Boveri Rev.* 1956, Vol. 43, No. 12, p. 515–24.

(4) K. Schröder: Grosse Dampfkraftwerke. Vol. 1: Kraftwerksatlas (1959), Springer-Verlag, Berlin.

Bibliography relevant to the subject but not cited in the article:

(5) H. Melan: Zukünftige Entwicklung der thermischen Energieerzeugung. Öst. Z. Elektrizitätswirtsch. 1954, Vol. 7, No. 4, p. 106–13.

(6) H. Melan: Series of articles on Korneuburg power station in Energiewirtschaft, Vienna, 1960, Vol. 1, No. 4, p. 9–33.

(7) K. H. Schüller: Kombinierte Dampf-Gas-Prozesse. BBC Nachr. 1959, Vol. 41, No. 10/11, p. 404–37.

(8) Montprofit: L'installation combinée gaz/vapeur en service a l'Usine Génératrice de Bône II d'Electricité et Gaz d'Algérie. Report 164 G1/22, World Power Conference, Vienna 1956.

(9) P. F. Martinuzzi: Gas-Steam Power Generation. ASME Paper No. 60—GTP-6 (1960).

(10) W. Karrer: Die seriegeschaltete Gasturbine im Heizkraftwerk. Diss. ETH, Zurich 1950.

(11) W. Karrer: "Dampf-Luftanlagen für gleichzeitige Erzeugung von mechanischer Energie und Wärme." *Schweiz. Bauztg.* Vol. 126 (1945), No. 12, p. 133–136.

(12) W. Karrer: "Die Ausnützung der Abwärme von Gasturbinen in Dampfanlagen." *Motortech Z.* Vol. 18 (1957), No. 6, p. 187–189.

Relevant Patents

(13) Swiss patents 246084 and 287354 (Brown Boveri).

(14) Maschinenfabrik Oerlikon: Swiss patents 245488, 275575 and 336648. Brown Boveri has acquired these patents.

(15) U. S. Patent 1978837, General Electric Co.

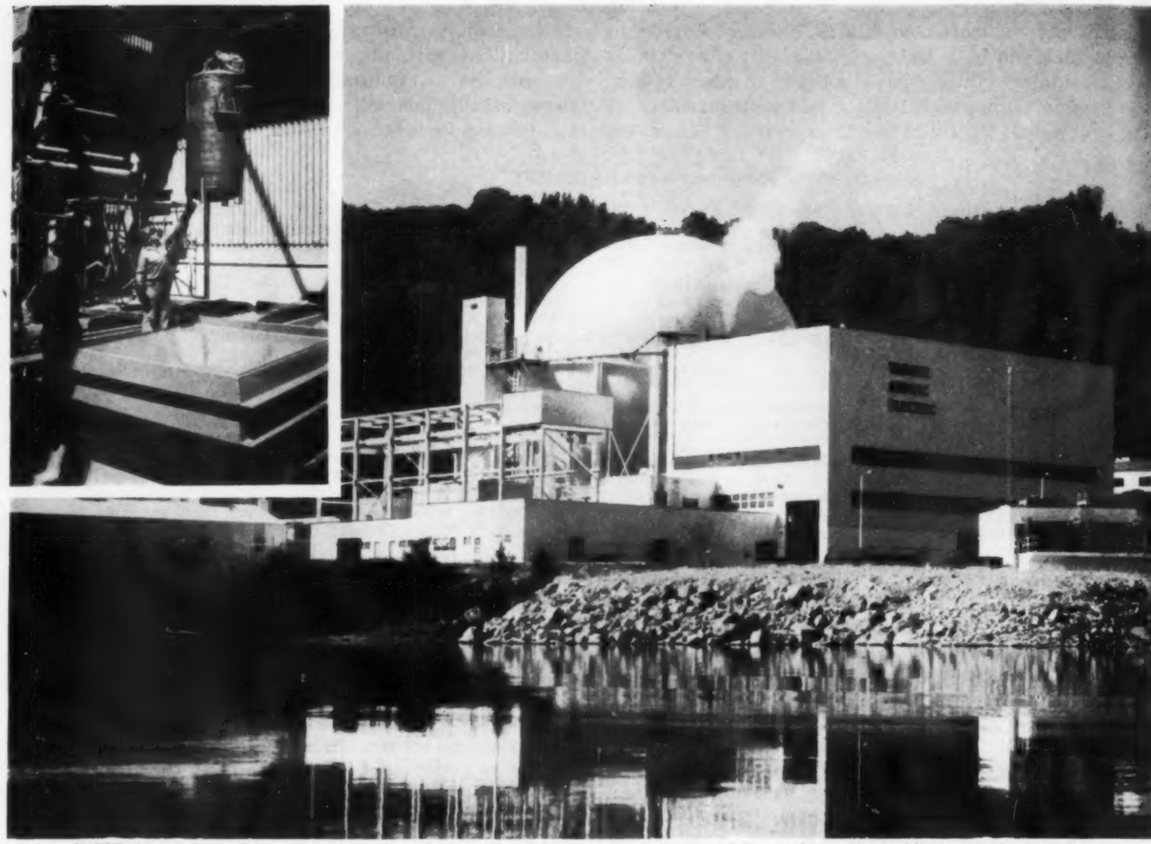
High-Speed Three-Color Pyrometer

The principle of a high-speed three-color pyrometer has been demonstrated by a prototype instrument developed by G. A. Hornbeck of the National Bureau of Standards. The prototype is capable of making 1000 individual temperature determinations per second in the temperature range 1000 to 3000 C with an uncertainty of about 1 per cent. The high-speed characteristics of this pyrometer will be of value in the measurement of temperatures of limited duration. Potential applications include the measurement of the temperature of missile components during firing tests, of ablating nose-cone materials, and with modifications, of exploding wires.

In essence, this instrument forms a spectrum of the radiation from the source, masks out all but the three required wavelengths, and presents these wavelengths to the detector sequentially. When operating at high speed, it is necessary to record the data with an oscilloscope, magnetic tape, or other high-speed recorder.

Certain limitations inherent in one- and two-color pyrometers have been eliminated in this instrument. Brightness temperatures measured with one-color pyrometers can be converted to true temperatures only if the spectral emissivities of the materials being observed are known. To avoid dependence upon knowledge of absolute values of emissivity, two-color or ratio pyrometers have been used in a number of applications. A limitation is once again encountered: the emissivities at the two wavelengths must be identical. Unfortunately, this is not always the case. True temperatures can be obtained through the use of three-color pyrometery, provided the emissivities are a linear function of the wavelengths selected. This criterion is generally true in the near-infrared region of the spectrum. Therefore, this instrument was developed to determine temperatures by measuring the intensities at three different wavelengths.

A unique system for the separation and measurement of three discrete wavelengths was incorporated in this instrument. Radiation from the source of interest passes through an entrance slit and is rendered parallel by a collimating mirror. The beam then passes through a prism and the resulting spectrum is brought in focus with a second mirror. The major feature of this optical system is a right-angle mirror placed in the vertical plane of the spectral image.

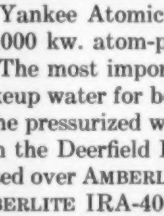


INSET: Installation of ion exchange unit to be used for deionizing water bypassed from primary loop while reactor is operating.

How do your ion exchange requirements compare with those of Yankee Atomic Electric?

AMBERLITE® ion exchange resins do three critical jobs for Yankee Atomic Electric Company, at this new 136,000 kw. atom-powered station in Rowe, Mass.: (1) The most important is to provide reactor-grade makeup water for both primary and secondary loops of the pressurized water reactor. Raw water is taken from the Deerfield River, clarified and filtered, then passed over AMBERLITE IR-122 cation exchanger and AMBERLITE IRA-400 anion exchanger. (2) Water is continuously bypassed from primary loop and passed over AMBERLITE XE-150 to remove ionic impurities formed by corrosion reactions. (3) AMBERLITE XE-78 is used to remove borate ions from primary coolant water after cold shutdowns (boric acid solution is used to stop the nuclear reaction when the reactor is cooled below normal operating temperature).

Whether or not your water conditioning requirements are as stringent as these, Rohm & Haas can supply you with ion exchange resins that will serve you efficiently and economically. We will gladly furnish technical information on our complete line of AMBERLITE ion exchange resins.



Write for this free booklet of case-history information on the many ways industry is using AMBERLITE ion exchange resins.

ROHM & HAAS
PHILADELPHIA 5, PA.

AMBERLITE

A Concept of Combustion Control for Firing Two Solid Fuels*

By CARL E. RODENBURG[1]

The Rust Engineering Company

Increases in fuel costs and technical advances in manufacturing processes have caused the management of many industries to consider the combustion of waste materials. Many boiler installations burning one solid fuel and one or more measurable fluid fuels, such as gas or oil, have been installed in paper mills, steel mills and oil refineries to name only a few of the industries involved.

RECENTLY, our engineering organization was retained to design and construct a boiler plant as part of an expansion program of a large eastern manufacturer of fine bond papers. In the past, peeled pulp logs had been delivered to the plant site. A large percentage of this wood was imported from Canada. Governmental export restrictions and the manufacturer's successful development of a hardwood pulping process, increased the use of local unpeeled pulp wood at this plant. When the expansion program was initiated, it was recognized that the capacity of the plant's debarking facilities must be increased.

Methods of disposing of the bark removed from the logs in a new wood room were under study before invitations to bid on the new boiler were issued. It was estimated that more than 40,000 lb of bark per hour would be available when the debarking units were operating at design capacity. Approximately 71 per cent of the bark is from hard woods and 29 per cent from soft. A heat value of 4379 Btu/lb at 52.96 per cent moisture was determined from laboratory tests of the combination of barks. It is predicted that about 58 per cent of the total capacity of 206,000 lb per hr, combined fuel capacity, will be produced by bark. Therefore, disposal programs which excluded the combustion of this material were not considered.

Several factors were definitely in favor of coal being selected as the second fuel for firing the new boiler. The plant site is located within trucking distance of several extensive strip mining operations. These mines produce a good grade of coal. It is predicted that the supply from these sources should be available for more than 30 years. The cost per ton, at present, is favorable at 26.2¢ per million Btu and is expected to maintain the same status relative to other fuels. All the existing boilers were fired with coal. Both stoker and pulverized fired units were in operation.

Inspection Tour

Having determined the fuels to be burned, a method of firing had to be selected. It was, therefore, decided that a visit should be made to several plants using these fuels. Only a limited number of such plants in the paper industry were in operation at that time. All told, fewer than ten installations were located in the USA and an equal number in Canada. Three plants were visited. Two of the installations were using spreader stokers, pneumatic distributors and chain grates. The third fired pulverized coal. Hogged bark supplied to this unit was distributed with pneumatic spreaders on a chain grate below the P C burners.

During these inspection tours it became apparent that the control of the combustion of these two fuels was very complex and required manual adjustment for several fuel variables. Poor fuel bed conditions, at-

[1] Staff Consultant, Engineering Department.

* Presented before the Solid Fuels Conference, ASME, Charleston, W. Va., Oct. 1960.

tributable to high air flow through the grates, were observed. Generally, low operating efficiencies were reported. This situation was due primarily to the failure to adjust the excess air flow to minimum requirements.

From these observations, it was concluded that the successful firing of coal and bark could be accomplished. Coal should be fired by a spreader stoker and bark by a pneumatic spreader. All fuel not burned in suspension should be burned on a traveling grate along with unburned combustibles reinjected from the dust collecting apparatus. Originally, the firing of unhogged bark was acceptable and equipment was purchased to perform this operation. Later studies which revealed a serious transport problem justified the selection of a pneumatic transport system suitable only for hogged bark. This change did not have any appreciable effect on this concept for a control system.

Objectives

It was also decided that the combustion control must include, if practical, the following desirable features:

1. Automatic adjustment for:
    a. Fuel moisture variations.
    b. Fuel quality variations.
    c. Kind of fuel supplied.
2. Excess air flow to be kept at a minimum for all fuel flow variations.
3. Bark flow to be uncontrolled.
4. Air flow through the grate be kept at a practical minimum.
5. Base load or major increment of all station loadings be carried on the new boiler.

Basic Fundamentals

After some study of these parameters our concept began to develop based on the following fundamentals. Since combustion is essentially a chemical reaction combining oxygen and a fuel, it was assumed that for any given steam load the air flow will remain constant. When firing the combined fuels at full load 206,000 lb per hr the heat release is predicted to be 821,000 Btu per sq ft of grate surface per hour. It is also estimated that when firing 10,346 lb of coal per hour and 42,522 lb of bark per hour about 293,000 lb of air per hour will be required. This air flow must be divided for most effective and efficient results between over-fire and undergrate service. Generally it is accepted by the industry that 85 per cent of the total air is required under the grate and 15 per cent as over fire air. When bark is made available we intend to determine the most practical ratio. Present operations show considerable fuel bed agitation which we believe is caused by too much excess air being passed through the grate and fuel bed. From observations it was concluded that the amount of fuel on the grate and its depth over the grate did not vary to any great degree. Therefore, the flow of air through the grate could be maintained at a minimum and constant for a given load. From reports made by control manufacturers' service engineers, it was learned that the air required under the grate varied very little with variations in the proportions of bark and coal on the grate. Again from observations it was determined that a considerable quantity of the fuel burned in suspension was not completely consumed, and it was returned to the grate as char. This feature, it is believed, tends to keep the heat release at the grate for a given load at a very stable and near constant level regardless of the fineness of the fuel. From observations made from the top of such a boiler, it was noted that considerable pulsing or puffing occurred as the hogged bark was introduced. These actions were accompanied by a lightening and darkening of the furnace which indicated wide variations in over-fire air demands.

Design

A preliminary flow diagram, based on these data, was then prepared as shown on Fig. 1. It was visualized that the forced draft fan inlet damper be adjusted from a manual control station. The air flow so created should be measured in the hot air duct. An impulse established by the measuring equipment to be transmitted to a controller on the firing equipment to create a coal flow. When the control impulse transmitted by the steam flow meter balances the air flow meter impulse a constant rate of coal flow will be established. An oxygen meter controls in a range of 10- to 20-per cent the over-fire air by throttling the damper of the fan installed for this service. When bark is introduced, the percentage of excess air will decrease. Immediately the oxygen meter reacts to correct this condition. As soon as the steam flow increases as a result of the combustion of the bark, then the rate of coal flow is decreased. Conversely, when the bark flow ceases, the coal flow will not be increased until the bark on the grate is consumed and the steam flow begins to decrease. Should the moisture or quality factors of either fuel change, the rate of flow of the coal will change as the steam flow changes. The coal flow increases as steam flow is reduced and decreases with an increases in steam flow. Since the boiler is to be loaded in excess of the rate at which all of the demand can be generated by bark alone, the coal fire acts as a pilot flame to ignite or maintain combustion of the bark. Furnace draft is to be maintained at a constant level by automatic control of the induced draft fan inlet dampers. This arrangement is the original concept of control to meet the conditions outlined.

Adjustment

It was recognized that, initially, the air-flow vs coal-flow ratio must be determined for several steam-flow rates. The calibration operation must be performed without over-fire air. A minimum flow of air through the fuel bed is desired; therefore, the lowest possible oxygen reading attainable is the objective. Smoking will be excessive but, as the operation may not be repeated unless the control system requires readjustment, it should be permissible under any code. Having made the setting, the oxygen meter and over-fire air fan damper adjustments may be made.

Modifications

Fig. 2 illustrates the system installed. Three modifications were made in the design of the system before it was approved for installation in the owner's plant. A substitute for the oxygen meter as a control instrument was requested. It was anticipated that high maintenance costs would be incurred to keep this item in dependable and satisfactory operating condition. A mechanical device replaces the oxygen meter. The ap-

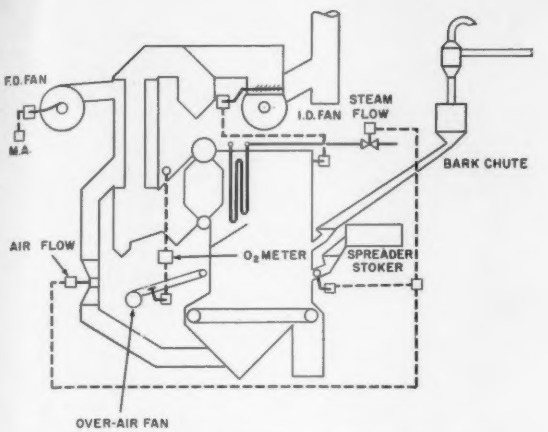


Fig. 1—Preliminary flow diagram based on early investigations called for metering shown above

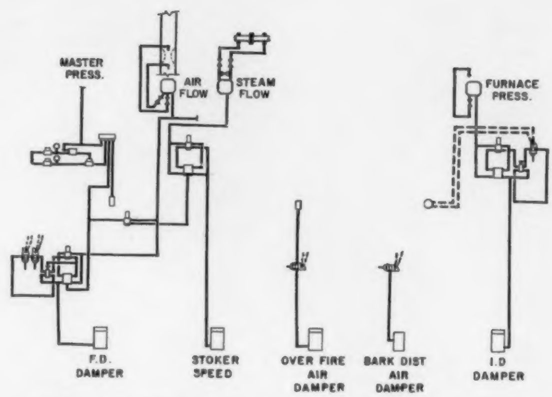


Fig. 2—Control line diagram of the actual system installed indicates range of equipment used

paratus consists of a flapper plate in the bark chute. When bark is imposed on the plate, its weight causes the plate to drop. This movement closes an electric switch which activates the over-fire air fan damper controller. The damper then opens to admit sufficient air to meet the over-fire air requirements when bark is introduced at its maximum rate of flow. This position is the maximum opening the damper is permitted. When the bark flow stops, the damper returns to its minimum position which is the point at which all the over-fire air requirements are satisfied for maximum steaming capacity firing coal alone.

Another modification was the addition of a device to sense changes in header steam pressure. It was felt that some insurance against an operator's failure to adjust the undergrate air flow for changes in station demands should be provided. This device will also select a new increment of the station load when other boilers are taken off or put on the line. For example, should the station header pressure rise, the equipment will act to reduce the load setting on the bark burning boiler by reducing the under-grate air flow. The remaining station units will then automatically be adjusted to carry a more normal load. Without the modification described they could be backed off the line unless the operator manually reduced the load on the bark burning unit. The reverse is also true. If the station header pressure decreased, the other station units would be forced into an overloaded status because the bark burning unit was generating at a fixed level. Normally, the control equipment is inactive between predetermined limits fixed by normal variations in station header pressure. When these limits are not exceeded, no effect is sensed by the other elements of the system.

A third modification was made after the boiler was put in operation and before bark was available. During this operating period, it was found that changing the system to permit the bark burning boiler to control station steam header pressure would simplify work procedures. Therefore, a system of switches was installed to bypass the dead band device described. The change has produced very satisfactory results when burning coal alone. It is possible that with a uniform and steady bark flow satisfactory results may also be obtained.

Possible Combinations of Fuels

While this concept was developed for the firing of coal and bark, it is conceivable that other combinations of fuels may be burned successfully. In every case, however, each fuel must be studied to evaluate its cost, availability and characteristics. Carefully select the fuel which is to be fired with a controlled flow. Give the same consideration to the one to be uncontrolled. The source producing a waste fuel may create a uniform, steady and dependable flow. Therefore, a relatively high-priced coal may be fired intermittently by a controlled feeder to maintain steam generation at a required level. Waste fuels such as bark, coffee grounds, nut shells, bagasse and corn cobs may be burned alone or in combination with coal, coke, lignite or other fuels.

Expected Results

As stated in the text, it is anticipated that higher operating efficiency can be attained by maintaining closer control of excess air. Less disturbance of the fuel bed can be achieved by keeping the flow of air through the bed at a practical minimum. Manual adjustments to correct for fuel moisture and quality changes can be eliminated. Intermittent flows of waste fuel can be handled without extensive and complicated control devices. All these advantages can be achieved by the system described. Bark was not made available for firing when this paper was prepared. Our concept therefore has covered only anticipated results.

My appreciation and gratitude are extended to Dr. D. T. Jackson of the Hammermill Paper Co. and to Mr. G. I. Seybold, Vice President-Engineering, the Rust Engineering Co. for their permission to present information.

For their invaluable aid, constructive criticism, encouragement, and support in preparing and editing this paper, I am deeply indebted to the following gentlemen:

The late Robert T. Sternberg, Power Superintendent, V. S. Oakes, G. S. Reed and R. W. Reynolds, Hammermill Co. Messrs. Wilkin, Fultineer, G. B. Motheral II, the Rust Engineering Co. H. Fulton of The Bailey Meter Co. E. C. Miller and L. P. Copian of The Riley Stoker Corp. Frank White, Richard Sample, and O. H. Keeling of the Copes Vulcan Division of Blaw-Knox Co.

ANOTHER

EASTERN CLEANING PLANT NEARS COMPLETION

This centrifugal dryer is one of the methods used at Keystone to control moisture.

Maintenance foreman adjusts control panel of the automatic oil treating machine.

Magnetite is thickened here before being returned to the heavy media washer.

Heavy media washer cleans the coarse coal—effectively reduces ash.

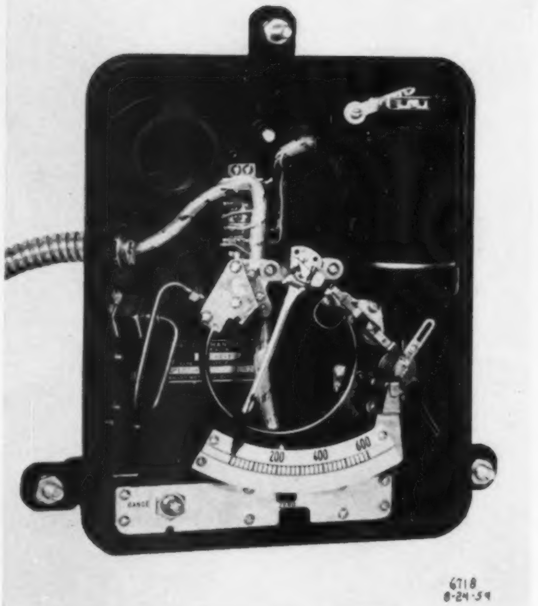


Fig. 1—Pressure transmitter using a bourdon tube as the primary element

By E. E. SWANSON†

Bailey Meter Company

In order to appreciate the manner in which electric control systems are applied to the various control loops of utility boilers on a system-wide basis, the individual components are described in detail. Examples are then given of typical control systems.

Application Of Solid State Electric Control To Utility Boilers*

THE rapidly increasing demand for electric power has stimulated the development of larger, more efficient generating units. As this trend has progressed, the control requirements of these new, larger units have become more complex, making it necessary to consider the control of the various process loops on a system-wide basis.

Until recently, the most frequently used electronic or electric controller has been a device giving proportional plus integral with sometimes derivative action, packaged with a transfer station in a panel mounted assembly. This concept is adequate for single element control arrangements consisting of one transmitter, one controller, one selector station, and one final control element. However, for the complex control systems now required for modern boiler-turbine generator units, the single-element approach becomes awkward since more controllers than selector stations are required. Also, controller settings are accessible to the operator from the front of the control panel, whereas he should normally limit his concern to manual-automatic transfer, manual control and possibly certain set-point adjustments.

* Presented before the Summer Instrument-Automation Conference and Exhibit, Toronto, Ontario, Canada, June 5–8, 1961, for the Instrument Society of America as Preprint No. 11-TC-61 and published in its entirety by permission of the ISA.

The purpose of the discussion which follows is to develop the basic techniques required in using a system approach to the application of solid state electric control to utility type boilers. In order to proceed it is first necessary to discuss briefly the design considerations and descriptions of some of the major components used in such a system.

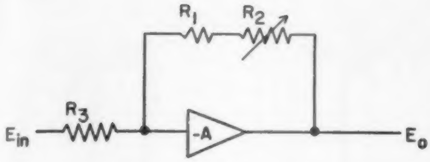
General

The control system herein described is a combination of electrically and electronically operated devices designed to produce variable outputs in accordance with desired or set point conditions. Included are the following major components:

1. Measuring elements and signal converters.
2. Controller and other computing or signal manipulating devices.
3. Hand-automatic selector stations.
4. Valve or drive positioning systems and operators.

Reliability is of prime importance and is achieved by making maximum use of static elements. That is to say,

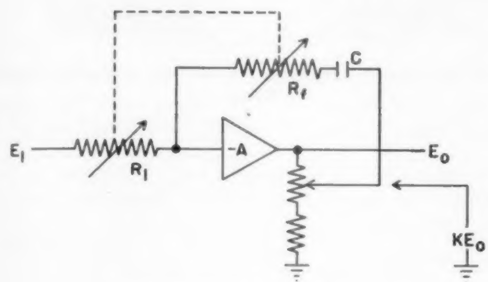
† Manager, Systems Engineering.



Proportional

$$\frac{E_o}{E_{in}} = -\frac{R_1 + R_2}{R_3}$$

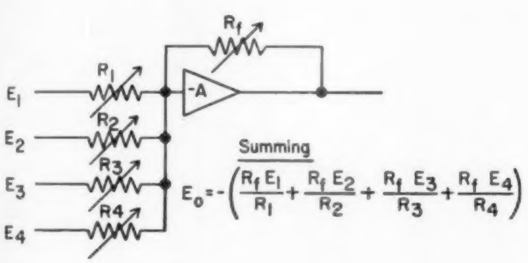
2a



Proportional Plus Reset

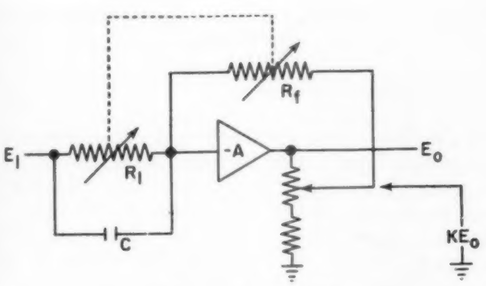
$$E_o = -\frac{1}{K}\left[E_1 \frac{R_f}{R_1} + \frac{1}{R_1 C}\int E_1\,dt\right]$$

2b



$$E_o = -\left(\frac{R_f E_1}{R_1} + \frac{R_f E_2}{R_2} + \frac{R_f E_3}{R_3} + \frac{R_f E_4}{R_4}\right)$$

2c



Proportional Plus Rate

$$E_o = -\frac{1}{K}\left[E_1 \frac{R_f}{R_1} + R_f C \frac{dE_1}{dt}\right]$$

2d

there are no moving parts except for valve or drive operators and certain transmitters. This permits almost infinite signal sensitivity by eliminating problems of backlash, dead band, and friction inherent in electro-mechanical devices. Circuit techniques used embody up-to-date designs with reliable industrial grade components de-rated by a least 50 per cent. Equipment is designed into individual functional modules to allow quick replacement and permit their servicing to be accomplished on a technician's bench. Input and output check points (test jacks) are provided on the fronts of all modules to allow rapid system trouble shooting and calibration.

Signal News

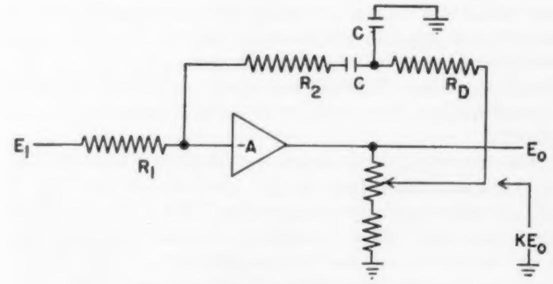
The system uses a zero centered d-c voltage as a standard signal throughout—that is to say, a signal which may vary from a negative potential to a positive potential as the measured variable, or demand, varies from zero to 100 per cent. All transmitters, controllers, selector stations, power operators make use of this standard signal. The range is a high level value measured in volts. The use of this type signal has the following significant advantages:

1. A d-c voltage signal is insensitive to a-c pickup in the interconnecting lines and independent of phase relationships.
2. Manipulation of signals for addition, limiting, biasing, auctioneering, is accomplished easily.
3. A single range voltmeter can be used to monitor measured variables, controller outputs, drive positions, throughout the system.
4. Very little shock hazard is involved.

5. Most position transmitters and flow, level, and pressure measuring transmitters utilize a differential transformer making it advantageous to use a simple demodulator to obtain a control signal.

6. Most transmitters using a current rather than a voltage system can have their outputs easily converted to a voltage signal.

7. The standard signal can easily be biased and/or ranged to voltage spans such as −10 to +10 volts, 10 to 50 volts, 5 to 25 volts.



Proportional Plus Reset Plus Rate

$$E_o = -\frac{R_2}{KR_1}\left[E_1 + \frac{1}{R_2 C}\int E_1\,dt + R_D C \frac{dE_1}{dt} + 2E_1 \frac{R_D}{R_2}\right]$$

2e

Fig. 2—Schematics, labeled for each, show typical actions and equation they obey

Transmitters and Signal Converters

The two general classifications which can be used for transmitters are: (1) those producing mechanical position outputs; and (2) those yielding voltage or current outputs.

Flow, level, and pressure transmitters use movable core transformer position transmitters giving electrical a-c outputs which are demodulated by silicon diode full wave bridge circuits to produce the standard d-c signal. Stability of this type transmitter is $\pm 1/4$ per cent over a 40 F to 140 F temperature range. Fig. 1 pictures a typical pressure transmitter using a bourdon tube as the primary element.

Transmitters such as thermocouples, resistance thermometer bridges and gas analyzers produce low level voltages which are amplified by solid state amplifier-demodulators, to produce highly linear standard d-c signal outputs.

All transmitters have floating ground so that the ground may be established at the control cabinet to give either direct action or inverse action to the final element.

Controllers

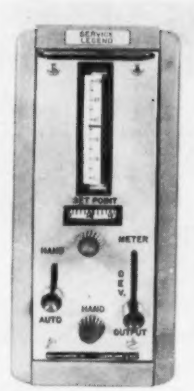
The controllers used in the system utilize d-c operational amplifiers with the proper input and feedback impedances to produce the desired control actions. Controllers are available as rate (derivative) action units, reset (integral) action units, proportional action units, algebraic summing action units or combinations thereof. Schematics of typical control action units are shown in Fig. 2. Controllers have adjustable gains (inverse of proportional band) of 0.2 to 10, reset rates of 0.1 to 50 repeats per minute, and rate times of 0.04 to 10 minutes. All control action units utilize the same operational amplifier design.

Selector Stations

In order for an operator to take over control of the system, selector stations are required. These stations provide the means for manual-automatic transfer and the means for manually adjusting the final drive element. Two specific types are available; (1) manual-balance, and (2) auto-balance. Each station consists of a mounting case with plug-in module. At the rear of the case and under a cover are screw type terminal blocks for making the necessary external connections. All components of the selector station itself are contained in the plug-in module. This allows a quick method for removal for calibration, maintenance and replacement when required.

The manual-balance selector station is shown in Fig. 3. Its operation is functionally the same as has been in use on current pneumatic systems. When the left hand lever is in the "Hand" position, manual control of the drive element is obtained by manipulation of the "Hand" knob at the bottom center of the station. The right hand lever permits the selection of either the drive position (output) or the measured variable (meter) to be indicated on the meter at the top. To transfer from automatic to manual, the right hand lever is placed in the "Deviation" position in order to compare the manual signal with the automatic signal. Center scale on the indicator at the top indicates zero deviation. Manipulation of the "Hand" knob will adjust the deviation to zero. Transfer to "Hand" may be made using the left hand lever when the deviation indicated is zero. To transfer to automatic, the deviation is checked and either the "set point" or the "Hand" may have to be adjusted to obtain zero deviation. The left hand lever may be transferred to "auto" when this zero deviation is observed. Selector stations are available with set point adjustment, bias adjustment or with neither.

The auto-balance selector station shown in Fig. 4, has no present counterpart in pneumatic control systems. Unlike the manual-balance selector station, no balancing for zero deviation is required. All that is required to make a transfer from manual to automatic or automatic



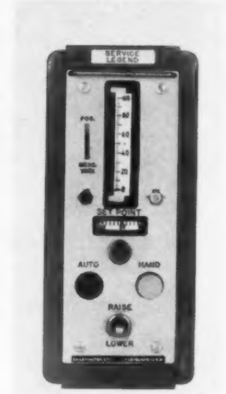


Fig. 3, left, manual-balance and Fig. 4, right, auto-balance selector stations

Fig. 5—Motor control circuit schematic diagram used for electric operators

Fig. 6—Equipment is fabricated as modules and can be plugged into system cabinet above

to manual is to press the appropriate pushbutton. An indicating light immediately above each pushbutton designates the current status of the selector station. Manual control of the drive element is obtained by jogging the toggle switch at the bottom center of the station. A lever switch to the left of the indicator at the top permits observing either the drive position or the measured variable. Stations with set-point, bias, or neither of these, are available. The use of the pushbutton approach used in the auto-balance selector station makes possible an easy tie-in with automatic plant start-up equipment since simple contact closures are all that is required to negotiate a transfer. Interlocking for any specific operating requirement is therefore possible.

Final Operator Actuators

There are available two types of final operators for the system—electrical motor, constant speed operators and pneumatic operators. The basic modes of operation of these are quite different.

Electric control drives used are of the gear motor type. These use worm gear reductions and are self-locking in case of power interruption. Fig. 5 illustrates the drive positioning system used with the electric operators. The output of the controller is compared with the drive position signal. If the two are not equal, the magnetic amplifier operates to energize the reversing starter to run the electric drive motor in the correct direction to cause the position signal to equal the controller signal. Thus the magnetic amplifier is an error or servo amplifier. Sizes available range from 100 ft lb torque to 2500 ft lb torque. The position transmitter employs a cam follower and cam to permit the linearizing of the drive characteristic.

When pneumatic drives or valve operators are employed, the voltage tie-back system is not used. Instead the controller signal is applied to a force balance electric to pneumatic converter which is located near the pneumatic drive or valve. For a full range of d-c signal input, air loading pressure output ranges of 3-15, 3-27, or 5-25 psi are available. A 30 psi air supply to the electric to pneumatic converter is required. Conventional pneumatic drives or valves may then be operated from the air loading signal obtained.

Auxiliary Devices

In addition to the transmitters, controllers, selector stations and drive elements, a number of auxiliary devices are required to perform specific non-linear functions in the system. Some of the commonly used types are:

1. Signal auctioneer. It is sometimes necessary to select the larger or smaller of two or more quantities. The signal auctioneer which uses a silicon diode in series with each signal input provides the required selection circuitry.
2. Signal Limiter. This device provides a means to limit the signal at any selected value. Actually each limiter has both a high and low adjustment with suitable setting knobs so that each may be adjusted independent of the other except that they may not overlap.
3. Set point and bias power supplies are placed in the system usually as series connected voltages to establish set points or to bias control signals.

The basic design is similar for all of the devices above. Minor modifications give each the desired characteristics.

Other auxiliary devices include a signal monitor which operates a pair of relays from a transistor amplifier for alarm purposes; a servo multiplier which uses a transistor amplifier and a shaded pole balancing motor with retransmitting slidewire to provide multiplying and auxiliary relay units for switching requirements.

System Design and Packaging

In the introduction it was stated that the nature of the new modern boiler units requires that control equipment be considered on an integrated or system-wide basis. The physical means of mounting the equipment must be designed in keeping with this philosophy.

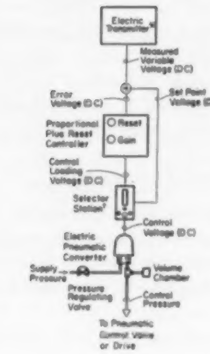
Fig. 6 shows a number of plug-in modules installed in a system cabinet which houses all equipment in the system except transmitters, selector stations and drive elements. All modules are connected to a wiring plane by "Blue Ribbon" connectors to allow easy removal. All interconnecting wiring is done at the wiring plane at the rear of the cabinet.

The individual modules are as wide as necessary to house the components. Module widths are in multiples of $1^1/_8$-in., are 11-in. deep and 7-in. high. A maximum of 15 such spaces are available in each row with a total of 10 rows possible in each cabinet. Normally, however, the last row or two at either the bottom or the top are needed for terminal blocks to which the necessary external connections are made. Filtered air is forced through the cabinet to cool the components and keep them clean.

Application

Over the years, experience with pneumatic control systems has resulted in the development of standard techniques for the application of this type of equipment. The application of electric control equipment requires the same knowledge of control theory as does the application of pneumatic control equipment. In other words, anyone who has a good understanding of boiler control requirements can learn to apply electric control equipment once he learns a few basic criteria. Following are the principles of applying electric control which are different or characteristic of this system:

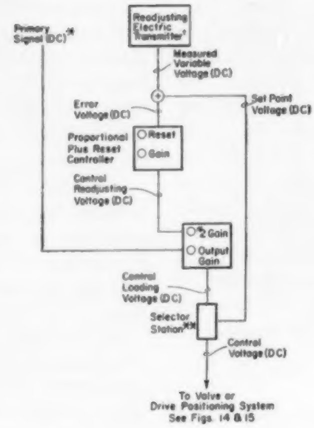
1. Wherever a set point or bias adjustment is required, a set point or bias power supply must be used.
2. Electric control action units are available in a number of different modes as outlined in the section under controllers. Some of these units are primarily for scaling, calibration, comparison, etc. While others provide the actual control functions such as proportional, reset and rate action. Pneumatic equipment has always combined some actions that are calibrations with control functions. Such is not the case with electric control. This achieves far greater flexibility but requires a little different thinking. Actually this separation simplifies the system into its two logical parts, calibration and control.
3. All control action units reverse the sign of a control signal as it is "passed through." This means that if the incoming signal is a positive d-c voltage, the output will be negative or will be changing in a negative direction. This feature is used many times to advantage when reversed action is required. It is, therefore, necessary to pay close attention to signal polarities to make sure that the final signal to the drive elements is correct. If not,



* Transmitter may be AC MCT with demodulator or RSW with DC power supply

† Indicator on selector station reads measured variable, drive position or transfer deviation as selected by meter switch on front

Fig. 7—Single element control with pneumatic drive element. The output of the controller becomes the drive position demand signal

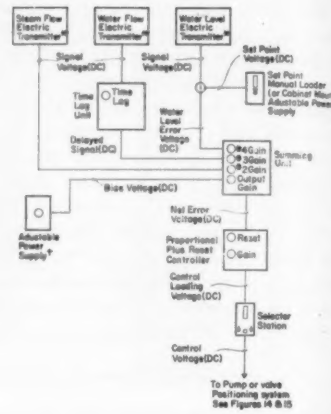


* Primary signal from action unit, selector station or electric transmitter (†).

† Transmitters may be AC MCT with demodulator or RSW with DC power supply.

** Indicator on selector station reads measured variable, drive position or transfer deviation as selected by meter switch on front.

Fig. 8—Two element control system with manually adjusted set point



Transmitters may be AC MCT with demodulator or RSW with DC power supply

Used only if steam flow and water flow transmitters are of unequal range. Otherwise omit and adjust summing unit gains to 1.0

Fig. 9—Standard three element control. Its schematic is shown in Fig. 10

the connections and hence the polarity of signals may be reversed by reversing the connections at either the transmitters or at the drive elements. Sometimes a signal reversal is required at a point where neither of the foregoing solutions can be used. In these few cases a proportional unit is used for sign reversal.

4. To compare two signals in order to establish an error signal, one of the two signals must be reversed to be of opposite polarity to oppose the other signal. This may be done with the inputs to a summing unit or by connection of a set point power supply in series opposition to an incoming signal.

5. Multiplication can be achieved by biasing the signal so that it is zero based, then either a proportional unit or a voltage dividing potentiometer can perform the multiplication after which the signal must again be biased back to the split range reference.

Some of the typical standard control arrangements are shown in Figs. 7 through 11 as follows:

Fig. 7 shows a single element control with pneumatic drive element. This simple control consists of a transmitter with series connected adjustable power supply located in the selector station to establish an error signal to the proportional plus reset controller. The output of the controller becomes the drive position demand signal to the electric to pneumatic converter. The air pressure from the electric to pneumatic converter is the control signal to a standard pneumatic drive element.

There is also a single element control with electric drive element. The control is identical to that in Fig. 7 except that the output of the controller is transmitted to a three position controller (magnetic amplifier) where it is compared with the drive position signal. The electric drive positioning system has been previously described under Final Operator Actuators.

Fig. 8 shows a two element control system with manually adjusted set point. In this system a primary signal such as that established by a steam flow trans-

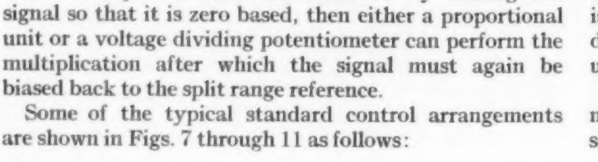
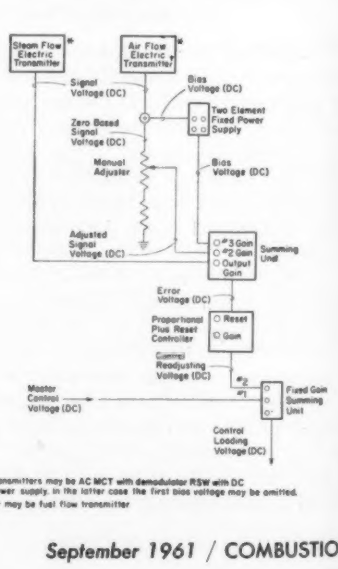


Fig. 10—This is a graphic illustration of the standard three element feedwater control

→

Fig. 11—Air-flow compensation system with automatic excess air adjustment



* Transmitters may be AC MCT with demodulator RSW with DC power supply. In the latter case the first bias voltage may be omitted.

† Or may be fuel flow transmitter

mitter is used to provide the drive position demand signal. In order to maintain a set value of another variable such as steam pressure, a transmitter with series connected adjustable power supply can provide an error signal to a proportional plus reset controller. The output of the controller becomes the correcting or readjusting signal which when added algebraically to the primary signal, modifies the drive position demand signal in order to maintain the set value of the second variable. The most common use of this scheme in utility boiler controls is for the so-called "Boiler Master" where the control signal is transmitted to both fuel and air drive elements for parallel operation.

In addition there is a two element control system with either manually or automatically adjusted set point. The control system is very similar to that shown in Fig. 8. A separate manual loader replaces the adjustable power supply in the selector station. With two transmitters and summing unit replacing the transmitter and this manual loader, the control system becomes the simplest form of fuel-air readjusting control. In this case one of the transmitters is for fuel flow measurement and the other is for air flow measurement. These two signals are compared in a summing unit to establish an error signal to the Controller.

Fig. 9 shows standard three element feed-water control. The control shown here employs a basic philosophy which has long since been established as tops in controlling feedwater to maintain boiler drum level. Feedwater flow is compared with steam flow to provide an error signal to a proportional plus reset controller. The output of the controller becomes the demand signal to the feedwater valve or pump speed control. This assures sufficient feedwater flow to meet steam flow demands. However in order to maintain a set drum level, an additional error signal is introduced by establishing a drum level signal and placing an adjustable power supply in series therewith. This second error signal is added to the first error signal to create a net error signal to the controller. As a further refinement to counteract the swells in boiler levels on load changes, a delay unit is used to introduce time lag to any change in the feedwater flow signal.

Fig. 10 is a graphic illustration of a standard three element feedwater control. This illustration graphically portrays the diagrammatic layout shown in Fig. 10 so that the various components may be associated in a physical sense.

Fig. 11 shows an air flow compensation system with automatic excess air adjustment from gas flow in a two fuel application using steam flow air flow as the basic air flow readjustment means. In two fuel applications, the calibration of the control system is normally adjusted for one of the two fuels to be used. When any of the second fuel is burned in parallel with the first fuel it is often necessary to alter the per cent excess air. Therefore the second fuel can be biased to give a zero voltage base and added with the steam flow air flow comparison to cause a reduction or an increase in air flow as more or less of the second fuel is used.

Summary

The application of solid-state electric control to utility boilers involves the same control philosophy as pneumatic control plus several simple factors, such as the signal reversal and the automatic transfer selector station. The decision of whether or not to apply electric control may depend at the present on planned use of other electrical systems such as data logging, scan-alarming, performance monitoring, sub-loop controls, or any combination of these elements of the fully automatic plant.

Engineering Educators Favor of Changes in Curriculum

A majority of the nation's civil engineering educators favors major changes in engineering education, including a pre-engineering program and extending the total period of education, it was announced by the American Society of Civil Engineers here.

The opinion of the educators was obtained in a mail ballot conducted by the Society. Results were analyzed by ASCE's Committee on Engineering Education, assisted by a special advisory group representing other engineering agencies concerned with education.

Balloting of the educators followed the 1960 Conference on Civil Engineering Education, held at the University of Michigan, Ann Arbor, to which official delegates from 140 schools with accredited curricula in civil engineering were invited. The educators voted on resolutions, all related to improvement in engineering education.

Voting was conducted in two categories: one ballot for the official delegates to the conference, and the second ballot to the civil engineering departments of the 140 accredited schools.

Among the conclusions reached after a study of the ballots were the following:

1. That there is an overwhelming sentiment for promoting the growth of graduate study in civil engineering and for the establishment of graduate professional schools of engineering.
2. That a majority is in favor of moving toward a pre-engineering program and in favor of extending the total period of education.
3. That an overwhelming majority is in favor of raising the standards of performance and ethics in the profession by taking a firm stand on these matters through the American Society of Civil Engineers and Engineers' Council for Professional Development, and in favor of taking an articulate position on the importance of basic scientific and cultural subjects.

The principal resolution, which was indicative of the general sentiments of the educators, served as the theme for the conference at the University of Michigan. It said in part:

". . . this conference favors the growth in universities and colleges of a pre-engineering program for all engineers, emphasizing humanistic-social studies, mathematics, basic and engineering sciences, to be followed by a professional or graduate civil engineering curriculum based on the pre-engineering program and leading to the first engineering degree."

Of the 90 official conference delegates voting, 60 per cent were for the resolution. In the civil engineering departments of accredited schools participating in the ballot, 467 educators voted for the resolution, and 356 against, with 95 abstaining.

Abstracts from the Technical Press—Abroad and Domestic

(Drawn from the Monthly Technical Bulletin, International Combustion, Ltd., London, W. C. 1)

Fuels: Sources, Properties and Preparation

Methane from Coal. F. J. Dent. *B.C.U.R.A. Quart. Gaz.* 1960, No. 42, 1–14.

The Ninth Coal Science Lecture in which the development of processes of complete gasification and the production of a gas of town gas quality was reviewed.

The Physical and Chemical Properties of Bituminous Coal Macerals. XII. Small Angle X-ray Scattering of the Macerals and their Cokes. C. Kröger and G. Mues. *Brennst-Chemie* 1961, **42** (Mar.), 77–83 (in German).

The inner surface of macerals and their cokes determined by X-ray scattering has been compared with that by the heat of wetting method; they are in good agreement.

Reducing Coal Degradation in Bunkers. Anon. *Iron and Coal Tr. Rev.* 1961, **182** (Apr. 21), 860–1.

An anti-breakage trunking forming a slot or rectangular channel down one side of the bunker is used to guide coal from the top to the outlet without pressure from the weight of the coal in the bunker causing degradation. The installation is specially recommended where a spiral chute is used for feeding the coal.

Steam Generation and Power Production

Acoustic Attenuation and Relaxation Phenomena in Steam at High Temperature and Pressure. D. D. Eden, R. B. Lindsay and H. Zink. *J. Engng. for Power* 1961, **83** (Jan.), 137–44.

Preliminary investigations were made with a fixed-path acoustic interferometer and steam of up to 450 C and 100 atm but the work done so far does not suggest a relaxation process which would have a significant bearing on high speed flow properties of steam.

Large Strains of Drum Heads Studied with Silicone Rubber Models. H. Fessler and J. J. Foreman. *J. Mech. Engng. Sci.* 1961, **3** (Mar.) 42–9.

The model experiments have shown that the effect of large strains on the bending moments in a drum head can be calculated if the relation between increase in head height and pressure has been determined and the bending moments for one pressure are known.

Efficiency of Coal-Fired Industrial Poilers. D. C. Gunn. *Engineering* 1961, **191** (Apr. 14), 534–5.

The tests were carried out on a vertical boiler rated at 4950 lb/hr and a horizontal boiler rated at 7000–9000 lb/hr and efficiencies with oil firing and coal firing (on a chain-grate stoker) compared. In the vertical boiler oil firing gave an efficiency of about 82 per cent, the best coal only 1.9 per cent less, in the horizontal boiler oil firing produced an efficiency of 84.9 per cent over a wide range of load whilst the best coal only 1 per cent less but over a much narrower range of load. This shows that with good coal almost the same high efficiency can be obtained as with oil if a modern appliance is used.

Thoughts on the Development of German Boiler Design since 1950. E. Duis. *Elektwirtsch.* 1961, **60** (Mar. 21), 183–91 (in German).

After a survey of general design trends, especially toward the forced flow boiler with high subcritical or supercritical steam pressure and temperatures around 1100 F examples of recent boiler design for larger power stations are described. Most of these are Benson boilers with outputs of 400–500 tons/hr, 190–210 atü and 535–545 C and slagging furnaces.

Post-War Development in British Water-Tube Boiler Design—II. K. R. Lenel. *Steam Engr.* 1961, **30** (Apr.), 225–30.

The second part mainly describes boilers for 30 and 60 Mw units as built in large numbers in the early post-war years. The two boilers with slagging furnaces for Padiham power station each rated at 860 klb/hr, 1600 psi and 1010/1005 F and a boiler rated at 830 klb/hr, 1600 psi and 1060 F for a 100 Mw unit at Castle Donington power station are also mentioned.

Some Dual Circulation Boilers. R. H. Paddon Row. *J. Inst. Fuel* 1961, **34** (Apr.), 143–52.

The reasons for introducing the dual-circulation boiler, definition of dual circulation and designs of such boilers are presented.

The Ejection of Water from a Tube Beyond the Critical Point of Water. E. M. Shchukin. *Energomashinostroenie* 1960, **6** (Dec.), 19–22 (in Russian).

The hydrodynamic parameters of a forced flow water-tube boiler are discussed from the point of view of hydrodynamic stability; a method is given for determining the minimum loading of the boiler. Various assemblies of screen panels are considered; graphs are given.

U.K.A.E.A. abstract.

From *C.E.G.B. Digest* 1961, **13** (April 15), 1069.

Lagging the Open-Air Poiler. Anon. *Pwr. Wrks. Engng.* 1961, **56** (Apr.), 295–9.

A system of boiler lagging has been developed which allows for the expansion and contraction of the boiler itself as well as the outside cladding under the effect of sun or cold winds. Particular attention has been paid to electrical insulation between outside aluminum sheets and steel lagging and cleading pins to prevent corrosion.

Solid Fuel Firing

Prevention of Low-Load Smoke from Spreader Stokers. R. B. Engdahl

and W. A. Erion. *Coal Utiliz.* 1961, **15** (Mar.), 15–16.

Smoke emission at low loads is caused by excessive cooling of the furnace and can be prevented by reducing overfire air in proportion to the fuel feed and all leakage of air into the furnace. Dust emission at low loads can be prevented by increasing the fuel bed thickness as load is decreased.

Liquid and Gaseous Fuel Firing

Atomization of Liquid Fuels for Combustion. P. Eisenklam. *J. Inst. Fuel* 1961, **34** (Apr.), 130–43.

Recent research has indicated that mass transfer (evaporation) has a controlling influence on atomization and the factors influencing rate of evaporation of drops and sprays are considered. The mechanism of disintegration of a liquid drop and means of obtaining clouds of finely divided drops are discussed. Data on performance criteria of atomizers such as flow rate, drop size and spatial configuration of the spray are presented.

Furnaces and Combustion

Application of Flow Research to Industrial Furnaces with Particular Emphasis on Soaking Pits. H. Boenecke. *J. Iron and Steel Inst.* 1961, **197** (Apr.), 283–95.

German research into flow in furnaces by means of models and its application to the design of industrial furnaces are described.

Investigation of a Two-Chamber Cyclone Furnace with Intersecting Jets. A. P. Kovalev and A. S. Ippolitov. *Energomashinostroenie* 1960, **6** (Nov.), 16–19 (in Russian).

A model is used for studying the effects of velocity and composition of the pulverized fuel on the motion near the burner. The system has two jets.

U.K.A.E.A. abstract.

From *C.E.G.B. Digest* 1961, **13** (April 15), 1086.

Water-Side Corrosion and Water Treatment

The Development of Boiler Feed Water Treatment—III. A. G. D. Emerson and F. R. Jarrett. *Steam Engr.* 1961, **30** (Apr.), 234–6

This last part deals with methods of water treatment for high pressure boilers by evaporation and ion exchange, respectively. Waters of low and medium solids content are preferably treated by demineralization, waters of high solids content by evaporation followed by polishing in a mixed-bed demineralizer. Final treatment with hydrazine and/or ammonia is usual to prevent corrosion by traces of dissolved oxygen.

Gas-Side Corrosion and Deposits

Slurry Spraying for the Control of Corrosion and Deposits in Oil-Fired Boilers. W. F. Cantieri and R. E. Chappel. *ASME Preprint* No. 60-WA-284 1960 (Dec.), 8 pp.

Reduction of high temperature corrosion and deposit formation of boilers fired by oil with high vanadium, sulfur and sodium content by additives mixed with the fuel or injected through the burners or ports not having proved successful the spraying of a slurry of additive and water through soot-blowers on to the superheater and reheater surfaces has been tried out and found to make the deposits sintered, spongy and porous. The deposits fell to the furnace floor in pebbles which did not fuse. Superheater and reheater tubes of the boilers on which this method was tried out first showed no signs of corrosion although some hangers and supports were attacked. Altogether more than 40 boilers of Florida Power and Light Co. are now so treated.

Flue Gas, Ash and Dust

Key Point Inspection, Electrical Indicators Save Time on Fly-Ash Precipitator Maintenance. R. W. Sickles. *Combustion* 1961, **32** (Mar.), 30–2.

It is suggested that maintenance of electrostatic precipitators is often either neglected or done unnecessarily and that it is sufficient to inspect a few important parts and consult electrical records before deciding on a complete overhaul.

Power Generation

Power Stations Sites in the West Riding. Anon. *Engineer* 1961, **211** (Apr. 14), 611.

Two sites each suitable for a 2000 Mw power station have been found, one next to the existing Ferrybridge power station and the other at Eggborough, both on the river Aire. The Yorkshire coal fields would be able to provide the 5×10^6 tons of coal for each station. A third site on the river Aire at Gowdall is being investigated and another on the river Don near the Thorpe Marsh power station now under construction.

U.S.S.R. Plans Superpressure Plant. Anon. *Power* 1961, **104** (Apr.), 153.

A power station containing four units is being planned each consisting of a boiler rated at 3800 klb/hr at 4300 psi and 1060 F with double reheat to 1050 F and 600 Mw cross-com-

pound turbogenerator. Fuel is lignite with a C.V. of 5300 Btu/lb, 35 per cent moisture and 16 per cent ash and annual consumption will be 12 million ton. The overall thermal efficiency will reach 40–43 per cent.

Power Plant Developments by the Victoria State Electricity Commission. Anon. *Engng. Boil. Ho. Rev.* 1961, **76** (Apr.), 104–13.

The state of Victoria, Australia, possesses one of the largest known deposits of brown coal, of which at least 17,500 million ton can be economically won in large-scale workings. This brown coal is used to produce gas and briquettes and as fuel in power stations. The plant installed at Yallourn "A," "B," "C," "D" and "E" stations, Morwell and Hazelwood stations is described. A 330 kv link exists between this generating system and the Snowy Mountains hydroelectric scheme for the exchange of power between Victoria and New South-Wales.

Fuel and Energy Required for Steelmaking in the Open-Hearth Furnace. R. Mayorcas and I. H. McGregor. *J. Inst. Fuel* 1961, **34** (Apr.), 153–6.

Materials, oxygen and heat balances for the o.-h. furnace operating with different proportions of scrap and hot metal and when using oxygen are presented. The influence of waste heat utilization for steam generation on fuel efficiency is discussed.

Adapting the Arrighi Power Station to Firing by Natural Gas from Lacq: Control and Regulation Equipment. Pt. II. P. Boulogne and R. Becquet. *Tech. Mod.* 1961, **53** (Mar.), 95–103 (in French).

The electrical controls for the regulation of gas preheat, fuel and air valves, and the burners and flame failure devices are detailed. The operation of the controls when firing coal and gas separately and simultaneously is explained.

Power and Heat for Finland. Anon. *K.S.G. Register* 1961, No. 5, 7–22 (in German).

The new Hanasaari power station near Helsinki in Finland is at present equipped with a 75 Mw A.E.G. turbogenerator supplied with steam by a K.S.G. boiler rated at 550 klb/hr at 1860 psi and 995/995 F. The boiler is designed for the separate or simultaneous firing of pulverized coal, heavy fuel oil and town gas and contains tilting corner burners consisting of 3 oil burners between 4 coal burners, each oil burner flanked by two gas burners. The convection pass is divided into two damper controlled passes, one containing the primary superheater, the other the primary reheater. The secondary superheater is composed of the tubes lining the furnace roof, upper front and side walls of the furnace and finally a radiant tube platen superheater. The secondary reheater lies in the pass from the furnace exit to the convection pass. The air preheater is of 3-pass cast-iron Kablitz design with a steam-heated preheater in front to raise the air entry temperature. Soot blowers are installed in the upper part of the furnace and convection pass which also contains a steel-shot-cleaner. The electrostatic precipitator has a bypass for use when only oil is fired. The thermal efficiency is 90–91 per cent when coal fired and 92 per cent when oil fired. Brief details are also given of a traveling-grate fired boiler rated at 364 klb/hr at 1963 psi and 975 F for a cellulose works, a vertical-cyclone fired boiler rated at 44 klb/hr at 600 psi and 797 F for a nitrogen works and a pulverized coal fired boiler rated at 243 klb/hr at 1430 psi and 986 C for a cement works.

The Power Station Mannheim A.G. W. Ellrich. *Energie* 1961, **13** (Mar.), 112–6 (in German).

Station I of the year 1923 has a total capacity of 12.5 Mw with steam parameters of 284 psi and 680 F is still operational and serves as a reserve. It also contains the first high pressure boilers ever installed in a power station, two boilers each rated at 132 lb/hr at 1430 psi and 887 F erected in 1927 which are kept as reserves until a new boiler is commissioned in 1962. Station II contains two natural circulation, single-pass boilers with slagging furnaces each rated at 440 klb/hr at 2490 psi and 986 F with double reheating of the steam by superheated steam to 968 F. The steam is supplied to a 43 Mw topping turbine and after reheating to two 41 Mw turbogenerators; the turbines each drive a 33 Mw three-phase (50 c/s) and a 15–18 Mw single-phase ($16^2/_3$ c/s) generator. Surplus steam from station I at 270 psi is expanded in a 67.5 Mw condensing turbogenerator installed in station II. The net heat rate of station II with double reheating is only 9000 Btu/kwhr. A new boiler rated at 1060 klb/hr at 2500 psi and 1004/986 F fired by 4 horizontal cyclones is under construction to supply a 55 Mw topping turbogenerator and a 67.5 Mw condensing turbogenerator for 3-phase (50 c/s) and a 40 Mw condensing turbogenerator for single-phase ($16^2/_3$ c/s) operation. It is intended to continue the use of station I for peak loads and as a reserve because of its exceptionally low generating costs.

Piratininga, the Largest Thermal Power Station in South America. Anon. *Electrique* 1961, **36** (Jan.), 8-12 (in German).

To the two 80 Mw sets of the Brazilian station have been added two 125 Mw sets with two 1000 F, 1740 psig boilers. Heavy oil for firing is pumped from the Petrobras refinery through a 40 km heated pipeline over a difference in level of 1150 ft.

From *C.E.G.B. Digest* 1961, **13** (April 15), 1057.

The Rheinhafen Steam Power Station Karlsruhe of the Badenwerk A.G. W. Leitner. *Energie* 1961, **13** (Mar.), 108–11 (in German).

This power station contains at present 3 units with a total capacity of 230 Mw; its ultimate capacity is 500 Mw. The first unit of 64 Mw is supplied by a Benson boiler with steam at 1635 psi and 975 F, the second 66 Mw unit by a Benson boiler with steam at 1635 psi and 1004 F and the third 100 Mw unit by a Benson boiler rated at 665 klb/hr at 2575 psi and 995/995 F; this latter boiler is provided with an 18-cornered slagging combustion chamber and 3 burners each in 6 corners, a regenerative and a plate-type air preheater to obtain a flue gas exit temperature of 266 F. Availability of the boilers has been 97–99% and the overall average net heat rate 10,300–9,600 Btu/kwhr.

Automated Plant Has One Operator. L. R. Eddins and J. L. Warmack. *Elect. Wrld.* 1961, **155** (Apr. 3), 49–51, 84.

Riverside station of the Gulf States Utilities Co. is now employed for peak load duty and the installation of automatic controls has enabled the reduction of personnel from 14 to 1 man. The equipment for automatic starting, including burner ignition, operation and shutdown and the operation performed by each part are described.

Coal Flow for Power Generation. F. D. Cooper. *Coal Utiliz.* 1961, **15** (Mar.), 18–9.

At the H. B. Robinson station of Carolina Power and Light Co. a 182 Mw turbogenerator has been installed served by a twin-furnace, controlled circulation boiler rated at 1350 klb/hr at 1900 psi and 1005/1005 F equipped with 5 bowl mills of 45,500 lb/hr capacity each supplying 40 tangential corner burners. Coal is stored in 5 silos with stainless steel bottoms and eccentric conical connectors and passed to the Easy-Flo Bituminous Coal Research units with eccentric outlet to the mills. Moisture of the coal has been up to 9 per cent but no hold up has been experienced. The station is controlled by a monitor and

computer supplied by 300 scanning points.

Plans for 580-Mw Unit Announced. Anon. *Elec. Wrld.* 1961, **155** (Mar. 27), 48. A 580 Mw unit with steam at 3500 psi and 1000/1025/1050 F is to be installed in the Tanners Creek station of the Indiana and Michigan Electric Co. to give it a total capacity of 1105 Mw. The unit is to be ready for commissioning in 1964.

TVA 900-Mw Equipment Contracts Are Resolved. Anon. *Elect. Wrld.* 1961, **155** (Mar. 27), 76.

TVA have announced award of an order to CE for a boiler rated at 6100 klb/hr at 2400 psi and 1050 F (with an option for a second boiler) to supply a 900 Mw cross-compound turbogenerator of which two are on order. The actual site has not yet been decided upon but the first unit is scheduled to be commissioned in 1964.

Should You Refrigerate Condenser Circulating Water? M. Bjorndal and A. Furreboe. *Pwr. Engng.* 1961, **65** (Mar.) 58–9.

It is suggested that by using a closed condenser circulating water system with evaporation refrigeration added about 50 per cent savings in capital cost, 50 per cent in pumping power and 4–5 per cent increase in thermal efficiency can be obtained. Evaporation of the refrigerant could be by waste heat in the flue gas, bleed steam or live steam. Two schemes are illustrated.

Instruments and Controls

Automation—The Application of Computers to Automatic Boiler Operation. G. W. Kessler. *Steam Engr.* 1961, **30** (Apr.), 221–4.

A review of the advantages to be derived by computer control of boiler operation and the programming of a computer for this particular purpose.

Central Control Rooms: Ideas Differ. B. G. A. Skrotzki. *Power* 1961, **104** (Apr.), 61–5.

Present opinions on control room location, layout and equipment differ so widely that it is not possible to establish a clear trend.

400-Channel Digital Recorder. Anon. *Chem. Proc.* 1961, **7** (Apr.), 38–9.

This instrument has been installed at Geertruidenberg power station near Rotterdam to scan 350 temperatures from 20 to 700 C and 50 other instruments. The input signal is compared with a reference value and if outside set limits an alarm is given. At certain intervals or by push-button

command the printer records one complete scan of the 400 channels. A similar instrument is to be installed in a Polish power station.

Services at a Large Chemical Works. Anon. *Pwr. Wrks. Engng.* 1961, **56** (Apr.), 310–7.

Continuous increase in demand for steam made the replacement of several older boilers at the Clayton Aniline Co. Ltd. works imperative. In a new boilerhouse three water-tube boilers each rated at 75/90 klb/hr at 625 psi and 800 F equipped with I.C.L. type L traveling grate were installed to supply two 5500 kw back-pressure (60 psi) turbogenerators. The exhaust steam is passed to the process mains, the high-pressure feed heater and after reduction to 15 psi, to the direct-contact feed heaters and deaerators.

Centrifugal Air Compressors Fill Needs of Large Central Generating Stations. M. Ragsdale. *Power* 1961, **104** (Apr.), 82–4.

The advantages of centrifugal air compressors for providing air for soot blowers, pneumatic instruments and controls and general services are outlined and a few recent installations in power stations described.

Nuclear Energy

Gas Cleaning in Nuclear Plants. H. U. Kohrt. *Chem. Ing. Tech.* 1961, **33** (Mar.), 135–8 (in German).

The various processes of cleaning gas containing radioactive solid or liquid particles are discussed with regard to their suitability and separation efficiency. Filters made of various materials, -2-stage electrostatic precipitators, drying processes, absorption or adsorption on activated carbon and molecular sieves and their application are described.

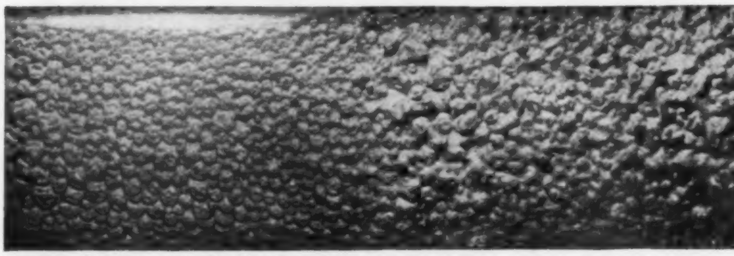
Pressurized Subcritical Facility. E. J. Hennelly. *Nucleonics* 1961, **19** (Mar.), 104–5.

To obtain higher moderator temperatures Savannah River Laboratory have installed a subcritical facility with self-pressurizing tank heated by steam coils to 215 C. Details of design and construction are given.

Ceramics-Thermal Conductivity. G. Arthur. *Nucl. Engng.* 1961, **6** (Apr.), 138–42.

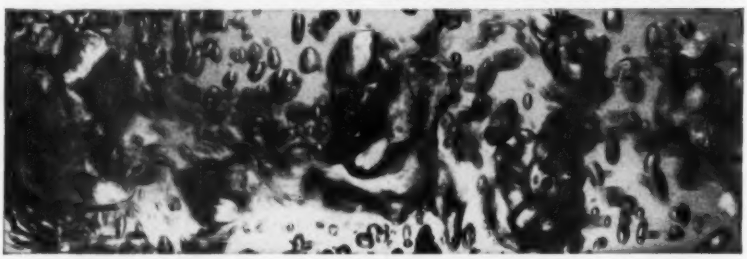
The increasing importance of ceramics in the production of fuel elements, moderators and structural elements is discussed and their densities, melting points, thermal neutron cross sections and thermal conductivity values of interest in reactor technology tabulated. Ways of increasing the conductivity are described.

CARRYOVER



Foam build-up in untreated boiler water

No foam in boiler water treated with Concentrol



MUST BE STOPPED!

Carryover of solids due to foaming is in most cases continuous. Suspended matter helps the foam layer build up so that steam bubbles, with their entrained boiler water, do not break quickly at the steam-water interface. Thus, boiler water is carried over into the steam mains.

Many plants with wet steam problems have determined that carryover must be stopped and have turned to the Bird-Archer Company for an economical solution. Bird-Archer research in stabilizing boiler water with high foam potential is backed by 60 years experience. The result is the development of a highly effective antifoam agent called CONCENTROL. Even when used in relatively small dosages Concentrol is effective in combining both resistance to hydrolysis or breakdown under boiler temperatures and pressures with ability to control foam.

Write for Bulletin on "Concentrol", and name of the Bird-Archer Service Engineer nearest you.

BA102

LABORATORIES · ENGINEERS · CHEMISTS

BIRD-ARCHER

WATER TREATING CONSULTANTS

The BIRD-ARCHER Company, 4337 N. American St., Phila. 40, Pa. / New York • Chicago

The BIRD-ARCHER CO. of California, 415 Brannan St., San Francisco•Offices in Canada and Mexico

Advertisers' Index

Aerotec Industries, Inc. . . . . *
Air Preheater Corporation, The 5
Anaconda American Brass Company 18
Allegheny Ludlum Steel Corporation . . . . . . *

Bailey Meter Company . . 26 and 27
Bayer Company, The . . . . *
Bell & Zoller Coal Company . . . 12
Bird-Archer Company 60
Buell Engineering Company, Inc. 28
Buffalo Forge Company . . . . . *

Cambridge Instrument Company 41
Clarage Fan Company 62
Combustion Engineering, Inc. . . . . Second Cover, 8 and 9
Compact Controls Company, Inc. 54
Cooper-Bessemer . . . . . . 22 and 23
Copes-Vulcan Div., Blaw-Knox Company . . . . 14 and 15
Croll Reynolds Engineering Co., Inc. 58

Dearborn Chemical Company 19
Diamond Power Specialty Corporation . . . . 10 and 11
Dow Industrial Service, Div. of The Dow Chemical Company *

Eastern Gas & Fuel Associates . . . . 46 and 47
Edward Valves, Inc. . . . . *

Fairmount Chemical Company 55
Foxboro Company, The . 20 and 21

General Controls Company . . . *
Graver Water Conditioning Company . . . . . . *
Grinnell Company . . . . *

(Continued on page 61)

Hagan Chemicals & Controls, Inc. .... *

Illinois Water Treatment Co.... *
Industrial Instruments Inc....... 56
Ingersoll-Rand Company..... 13

Johns-Manville............. *

Koppers Co................ 17

Manning, Maxwell & Moore, Inc. 16
Minneapolis-Honeywell..24 and 25
W. K. Mitchell & Company.... *

Nalco Chemical Company.... *

Pennsylvania Crusher Div., Bath Iron Works Corp.......... 4
Pfaudler Permutit Inc......... *
Powell Valves.............. *

Refractory & Insulation Corporation................ 61
Reliance Gauge Column Company, The............... 57
Republic Flow Meters Company................... *
Reliance Instrument, Div. of Electro-Mech Corp......... 59
Republic Steel Corporation.... *
Research-Cottrell, Inc......... 6
Richardson Scale Company... *
Richardsons, Westgarth & Co. Limited................. *
Rohm & Haas Company...... 42

Standard Tube Co., The...... 2
Stock Equipment Company.... *
Sumco Engineering, Inc. Third Cover

Valley Camp Coal Company.. *

John Wood Company....... *
Worthington Corp........... 3

Yarnall-Waring Company.... 7
Yuba Consolidated Industries, Inc...............Fourth Cover